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SPECIAL ISSUE

Emerging Technologies 2008

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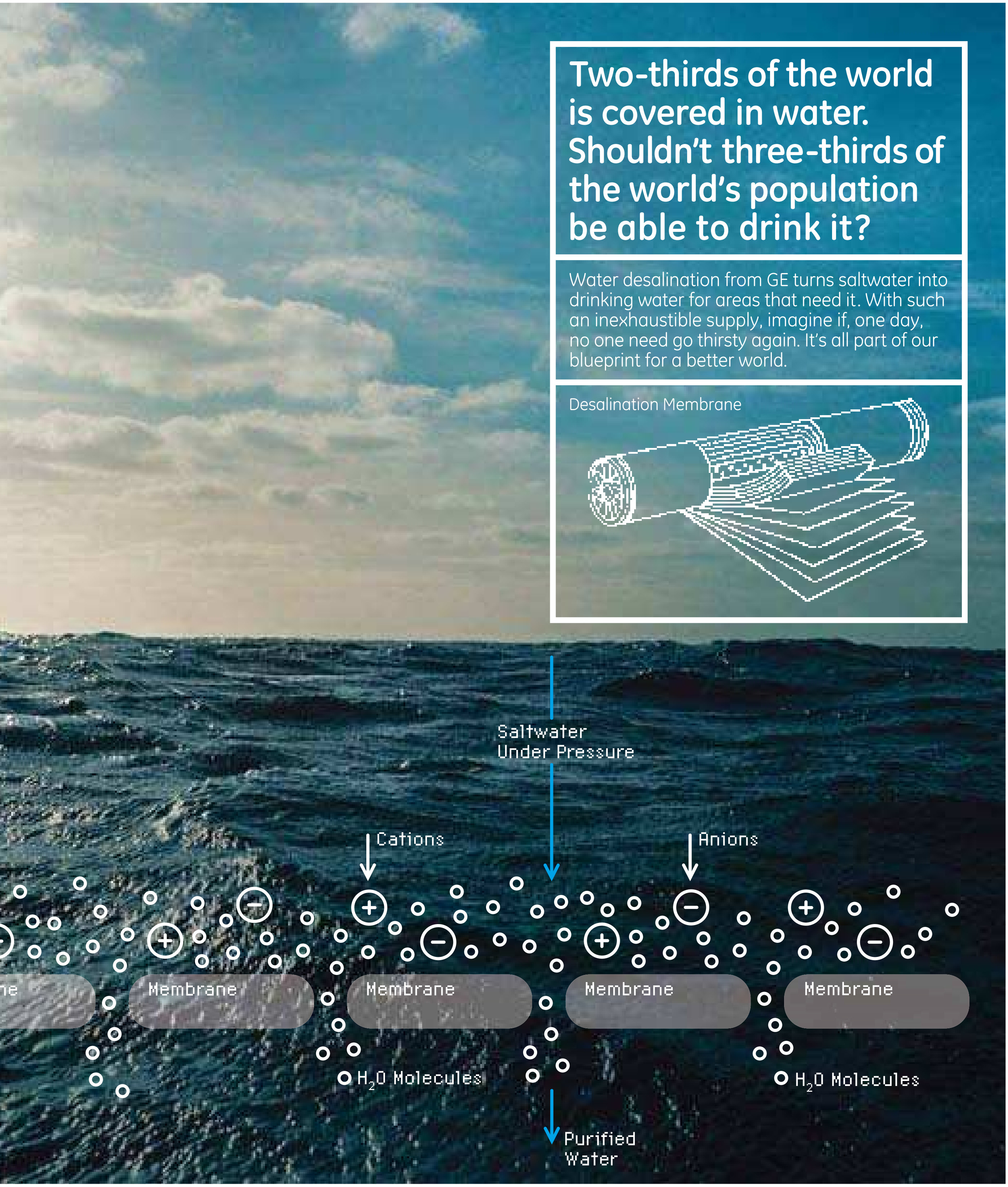

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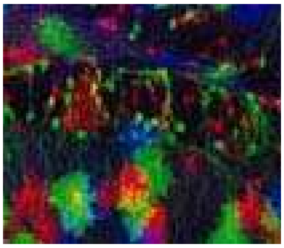

COSKATA (DEMO); BRODY CONDON (DIGITAL ART); JEAN LIVET, JEFF LICHTMAN, ET AL. (TR10)

/TR10

Behind every great innovation is a great innovator. We've got video of the researchers who made the TR10 possible, explaining and demonstrating their work. See Harvard professor Jeff Lichtman display his complex brain-wiring diagrams, which are at the core of the emerging field known as connectomics; watch MIT's Marin Soljačić explain the motivation behind WiTricity, a technology designed to charge battery-powered devices wirelessly; view a nanotube radio in action.

/DEMO

This issue's Demo looks at the process that Coskata, a startup based in Warrenville, IL, uses to create ethanol from wood chips, old tires, and garbage. William Roe, Coskata's CEO, walks the reader through the company's lab, explaining how the novel technology operates; Vinod Khosla, one of the world's most prominent venture capitalists and a major investor in Coskata, describes the benefits of the technology.

/HACK

The Kindle, Amazon's new wireless e-book display, could finally convince many readers that the time has come to go digital. In a video demonstration, we explain the working of the Kindle's interface and special features, such as the ability to annotate.

/EXPANDABLESILICON

We'll show you how a new kind of computer chip stretches to cover large areas. Visit our website to see the chip's silicon coils unspool, spreading out a network of processors.

/DIGITALART

Explore some of the work that the Whitney Museum of American Art's Christiane Paul discusses in her essay about digital art. See the figures in Brody Condon's *Resurrection* move, and watch John Gerrard's *Dust Storm (Dalhart, Texas)* unfold.

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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

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JEFFREY MACINTYRE wrote this month's feature on Photosynth, an application being developed by Microsoft that was demonstrated, to great approval, at the 2007 Technology, Entertainment, Design Conference in Monterey, CA *("Microsoft's Shiny New Toy," p. 76)*. Photosynth can create a navigable 3-D tableau of a place—say, Notre Dame Cathedral—by processing multiple photos of it found on websites such as Flickr. "I was drawn to the story of Photosynth because it sounded so preposterous," says MacIntyre. "I was told someone had broken the frame between what we think of as the media of photography and of video. Photosynth is, in its feel, a hybrid of both, and the early demos excited the imagination of everyone I know who saw them. What's more compelling is that none of us can quite predict where its formal innovations will lead. Photosynth feels like only the beginning of something far bigger." MacIntyre writes on culture, science, and technology for publications such as the *New York Times*, *Wired*, Slate, the *Boston Globe*, and the *San Francisco Chronicle*.

CHRISTIANE PAUL is adjunct curator of new-media arts at the Whitney Museum of American Art in New York City. In this month's essay *("Art Games," p. 82)*, she introduces us to pieces of art that use digital technologies as both subject and medium. "A lot of my work focuses on integrating digital art, which still exists mostly on the fringes of the traditional art world, into 'art at large,'" Paul says. "Digital art has been around for more than 40 years, and its history connects to other media throughout the past century. I am very interested in digital art projects that explore their medium in relationship to more established art forms—such as painting, photography, and video—and show how new technologies are changing our 'image world.'" Paul has written extensively on new-media arts and has lectured internationally on art and technology. A revised and expanded version of her book *Digital Art* will come out this year. She teaches as an adjunct professor in the MFA computer art department at the School of Visual Arts in New York, the Digital+Media Department of the Rhode Island School of Design, the Berkeley Center for New Media at the University of California, Berkeley, and the San Francisco Art Institute.

JENNIFER CHU profiles Marin Soljačić, an MIT physicist who is looking to do for power what wireless networks have done for the Internet: cut the cord *(p. 62)*. Soljačić and his team are developing technologies to wirelessly power devices such as laptops, cell phones, and iPods; their work is celebrated as part of this year's TR10. Inventor Nikola Tesla advocated wireless power transmission back in the 19th century, before vast networks of cables were strung up to deliver electricity around the world. "Now," says Chu, "so many of us carry around wires and chargers along with our various devices that researchers are realizing it's time to shed the weight of these wires." Chu spent six years as a producer for National Public Radio and is now a science writer based in Somerville, MA.

SUE TALLON photographed the image you see on our cover. "We worked on several concepts over the course of a few days," says Tallon. "Sometimes it takes days of playing with materials and sets before you find yourself pulling back to the basic elements of an image or concept."

Born an "Anglo-Argentine," Tallon now lives in San Francisco. She has been a professional photographer for 20 years but considers herself "more of a picture maker than a picture taker."

BIOFUELS

As David Rotman states in his article on biofuels, the conversion of biomass to liquid fuel is energy intensive—just like the conversion of coal or any other solid fuel to liquid fuel ("The Price of Biofuels," January/February 2008). That implies that the quantity of liquid fuel from biomass and the carbon dioxide released in the production process strongly depend upon the energy source used in the conversion process.

Each year, the United States could produce about 1.3 billion tons of renewable biomass for use as fuel. Burning it would release about as much energy as burning 10 million barrels of diesel fuel per day. If converted to ethanol, the biomass would have the energy value of about five million barrels of diesel fuel per day. The remainder of the energy would be used by the biomass-to-liquids conversion plant. If a nuclear reactor or other energy source provides the energy for the biomass-to-liquids plants, the equivalent of over 12 million barrels of diesel fuel can be produced per day. If our goal is to end oil imports and avoid greenhouse-gas releases, we must combine biomass and nuclear energy to maximize biofuels production.

Charles Forsberg
Corporate fellow,
Oak Ridge National Laboratory
Oak Ridge, TN

JOHN HOCKENBERRY AND NBC

In "You Don't Understand Our Audience" (January/February 2008), former *Dateline* correspondent John Hockenberry writes that he called NBC's parent company, GE, in early 2002 to request help in obtaining an interview with the family of Osama bin Laden. Mr. Hockenberry writes that he was rebuffed by a "senior corporate communications officer." I handled this issue for GE. While it's possible I got a call from Mr. Hockenberry, I don't remember one.

Nonetheless, if he did call, he would have received the same answer he says he got: "No." GE does not and should not involve itself in the news-gathering process of NBC. I am surprised Mr. Hockenberry believes otherwise. More to the point, he was certainly free to pursue this interview without GE's help. Other journalists got to the bin Laden family on their own. For example, NBC's Matt Lauer won an Emmy for his interview with Osama bin Laden's brother.

Gary Sheffer
General Electric
Fairfield, CT

John Hockenberry responds:
I'm sorry Mr. Sheffer doesn't recall speaking to me. Anyway: it seems hard to maintain that GE has no role in the editorial content of NBC when GE executives regularly agree to appear on CNBC and MSNBC. Presumably, GE executives believe some public interest is served by their appearances. I applaud Matt Lauer's 2004 interview, but surely it would have had even more value in January 2002. Mr. Sheffer apparently believes no public interest would have been served by helping facilitate such an interview four months after September 11.

John Hockenberry's excellent essay has a small error. Edward R. Murrow's wartime reports from London were sent across the Atlantic by short-wave radio, not cable. Telegraph service was available by cable at the time, but the first cable for voice traffic was TAT1, completed in 1956. The error caught my attention because in 1958, as a student, I worked at the U.K. Post Office Research Station at Dollis Hill, London. TAT1 was a joint effort by the post office, AT&T, and Bell Labs; the engineers in my department were happy to educate me on their achievement.

Bruno Vieri
Rancho Palos Verdes, CA

DIGITAL BUILDINGS

Some architects may be using new geometries to build exotic buildings ("The Building, Digitally Remastered," January/February 2008), but like the fins of a 1959 Cadillac, many new buildings' most prominent features will in time become laughable. Unfortunately, it isn't easy to send architectural monstrosities to the wrecker.

Sherwood Stockwell
San Francisco, CA

NORMAN BORLAUG

In his article about the work of Norman Borlaug, John Pollock describes the reasons for the Green Revolution's failure in Africa as "complex" ("Green Revolutionary," January/February 2008). Actually, they are pretty straightforward. Pollock describes some of them: lack of irrigation, very unproductive soil, corruption, and poor roads. But there are more: malaria and AIDS, poor education, lack of navigable rivers, and lack of electricity. It's the solutions that are complex.

Mike Quinn
Austin, TX

QUANTS ON WALL STREET

Bryant Urstadt's very interesting article about the role of quantitative financial engineers in the summer's troubles on Wall Street misses a point ("The Blow-Up," November/December 2007). As automatic securities trading increases its share of all trades, all the "quants" will be doing is modeling each other's models. The only way out of such infinite recursion is social: manipulation of prices by an elite whose techniques will resist regulatory supervision. Such gaming of prices via buried signals has already been seen in airline ticketing.

Gregory P. Nowell
Niskayuna, New York

CORRECTION

"The Price of Biofuels" (January/February 2008) should have stated that nitrous oxide (not nitric oxide) is produced in the cultivation of corn.

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NOTEBOOKS

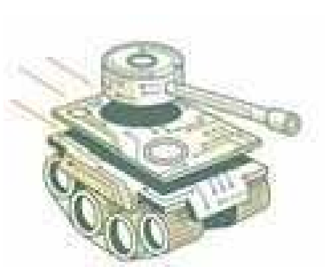
MILITARY

Network Warfare

JOHN ARQUILLA EXPLAINS WHY NEW MILITARY TECHNOLOGIES REQUIRE NEW ORGANIZATIONS.

FOR DECADES, the U.S. military has been working to move information ever more swiftly from "sensor to shooter." The more quickly targeting data is relayed, it is thought, the more likely our weapons are to hit the enemy. Making this process smoother and faster has been a fundamental aim of the advocates of "network-centric warfare," a concept many consider crucial to the "revolution in military affairs."

This movement, championed most ardently by the late Vice Admiral Arthur Cebrowski, who was director of the Office of Force Transformation in the U.S. Department of Defense from 2001 to 2005, has attracted support well beyond his acolytes. That's because warfare has shifted away from massed, set-piece battles between similar forces. Instead, nearly all conflicts since the end of the Cold War can be described in terms of swarming "hiders and finders." Combatants stay hidden, pop up to strike, and then disappear until they attack again.



This change has been most apparent in the rise of anticolonial guerrilla wars over the past half-century. In these conflicts, insurgents remain hidden—swimming in "the sea of the people," as Mao put it. Conventional militaries have lost most of their wars against such enemies.

Today, this hider-and-finder dynamic has become even more dominant, and the conflicts in Iraq and Afghanistan, as well as the global hunt for al-Qaeda operatives, place an extraordinary premium on knowing where the enemy is and what he is doing. This realization has spurred increased emphasis on rapid collection and dissemination of timely, targeted information about the enemy *(see "A Technology Surges," p. 70)*.

The years since September 11, 2001, have seen remarkable technical advances in information systems, from sensors and communications links to weapons-guidance packages. For example, I participated in creating a "surveillance and target acquisition network" that allowed real-time sharing of voice, video, and text between ground forces, pilots, and unmanned aerial vehicles like the Predator. Today, new systems are being fielded to allow soldiers to enter data on the spot—even during battle.

These technologies are wonders, but generally they have not been accompanied by shifts in military doctrine and organization. The result: a tidal wave of data is being created that can swamp systems still organized around large units (such as army divisions, naval strike groups, or air force wings) whose goal is to apply "overwhelming force" at some mythical "decisive point." Generally speaking, these large units cannot quickly disseminate the information they collect throughout their networks and then allow smaller constituent parts to swarm against insurgents.

This disjunction between technology and organization was one reason we floundered in Iraq from 2003 to 2006. But a shift began last year, away from big units on supersized forward operating bases to a network of small outposts. The latter's tiny but well-informed garrisons put a dent in the insurgency with a multitude of small-scale swarming raids on terrorist cells. At last, tactics and organizations had emerged to exploit the possibilities implied by advanced technological functions.

But this process has indeed only just begun. We face the risks of overemphasizing technology and leaving the hard-learned lessons of Iraq behind—just as our knowledge of unconventional warfare withered after Vietnam because we preferred to prepare for large, set-piece battles. Then, we fell in thrall to the allure of precision-guided weapons systems. Now a similar enchantment accompanies a range of information technologies. It is a spell that can be broken only by remembering that new organizational forms and practices must develop along with new tools. TR

JOHN ARQUILLA IS PROFESSOR OF DEFENSE ANALYSIS AT THE NAVAL POSTGRADUATE SCHOOL. HIS NEXT BOOK, *WORST ENEMY: THE RELUCTANT TRANSFORMATION OF THE AMERICAN MILITARY*, WILL BE PUBLISHED IN APRIL.

E-BOOKS

What's Wrong with the Kindle

JASON EPSTEIN SUSPECTS THAT THE MARKET FOR ELECTRONIC READERS WILL BE LIMITED.

NO ONE CAN doubt that digitization and the Internet, together with various factors intrinsic to the publishing industry, will radically transform the distribution of books: books can now be transmitted directly from writer to reader, eliminating much of the traditional publishing supply chain. Research, technical data, and the contents of dictionaries, manuals, certain journals, and encyclopedias of all kinds can now be sent to users' screens, item by item, on demand. This largely ephemeral material

HARRY CAMPBELL

need no longer be distributed in book form.

But for books that embody the ancient and ongoing dialogue that constitutes civilization, the format of printed and bound sheets is optimal and inescapable. True, a marginal market of indeterminate size may exist for handheld screens, serving some readers of seasonal fiction and nonfiction. However, the assumption that because content *can* now be transmitted electronically most books hereafter *will* be read on screens overlooks such factors as cost, convenience, reliability, and human nature, as well as the peculiar nature of books.

In Jonathan Swift's *Gulliver's Travels*, Lemuel Gulliver encounters the airborne island of Laputa, inhabited by so-called projectors—what today we would call inventors. The projectors are growing cucumbers on the theory that because they absorb heat and energy from the sun, cucumbers can replace traditional sources of warmth and light: biofuels 300 years *avant la lettre*. Gulliver also wonders why Laputan coats fit badly, until he visits a tailor and finds himself being fitted by compass and quadrant.

The new Kindle from Amazon *(see Hack, p. 94)* and its many failed predecessors are Laputan biofuel production and tailoring. Take, for example, the Kindle's price of $400: the first book downloaded will cost the reader $410, assuming $10 per download. This means that the first 20 books a reader buys will cost $30 each, the first 40 will cost $20, and so on—by which time the device will probably have failed, gotten lost, or been replaced by a newer model. Or consider function. The designers of handheld readers aim to approximate as nearly as possible the characteristics of a physical book—including, I am told, pages that actually feel like paper; but why bother, when the physical book already embodies these characteristics to perfection?

The most rational form of digital transmission is not an electronic reader posing as a book but an actual library-quality paperback that has been printed, bound, and trimmed at low cost on demand, created from a digital file at point of sale by a machine like an ATM. Test versions of this machine, sponsored by On Demand Books, of which I am cofounder, are or will soon be making books in several locations. A commercial version will be ready for general distribution this summer. TR

JASON EPSTEIN WAS THE EDITORIAL DIRECTOR OF RANDOM HOUSE FOR OVER 40 YEARS AND A COFOUNDER OF THE *NEW YORK REVIEW OF BOOKS*. IN 2004, HE COFOUNDED ON DEMAND BOOKS.

ENERGY

Mining Pathways for Biofuels

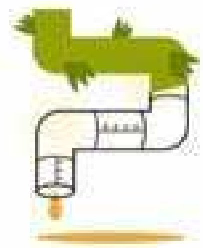
VINOD KHOSLA EXPLAINS THE EXCITEMENT OVER NEW WAYS TO MAKE FUELS.

THE WORLD OF fuel chemistry and production is undergoing exciting change. The range of possible biofuels includes butanol, cellulosic gasoline, cellulosic biodiesel, cellulosic "biocrude," and many more. We will be able to remove a hydroxyl group here, add a hydrogen there, and create a longer or shorter carbon chain to optimize fuels.

Researchers and innovators from disparate fields are coming together to work out a new approach to biofuels. This "innovation ecosystem" is replacing the traditional energy research organizations and companies, which have been unable to make sufficient progress. While some common chemical and biological pathways, such as the biological ones used to ferment sugar for ethanol, have long been used successfully in biofuel production, others pathways—such as those that enable the thermal and catalytic conversion of biomass—await technology innovation. The companies working to deliver the necessary breakthroughs range from small, privately funded startups to behemoths such as BP.

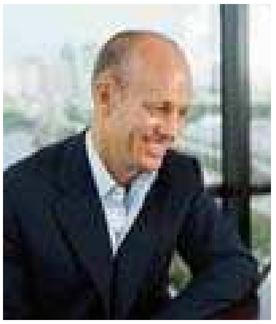
Important work is under way. LS9 is using synthetic biology to move pathways from plants into bacterial cells, with the goal of making petroleum from the fermentation of cellulosic feedstocks. Amyris, a company that began working on the malaria drug artemisinin, is transforming itself into a biofuel company using the same technology platform. Gevo is now taking on BP and DuPont in the race to commercialize butanol *(see "Cellulolytic Enzymes," p. 52)*.

Range Fuels has developed an anaerobic gasification technique to convert biomass into ethanol. Elsewhere, a number of researchers speculated that they could improve on Range's syngas-to-ethanol catalytic-conversion process by replacing it with microbes *(see "Ethanol from Garbage and Old Tires," p. 96)*. Coskata was born as a science experiment with a license to the technology from the University of Oklahoma and Oklahoma State University, a few million in seed funding, and a few great researchers.



A wide variety of biofuel processes are being tried in two important areas: designing new microbes and enzymes with the latest technologies, such as synthetic biology, and using fresh catalysts and new approaches for gasification and catalysis. These and other advances in biofuels have happened in just the last few years. Imagine what new ideas the innovation ecosystem will bring to the development of biofuels in the next decade. TR

VINOD KHOSLA IS THE FOUNDER OF KHOSLA VENTURES, A VENTURE CAPITAL FIRM THAT HAS BACKED A NUMBER OF BIOFUEL COMPANIES, INCLUDING LS9, AMYRIS, GEVO, RANGE FUELS, AND COSKATA.



How to Stay Young

THE EASY PART IS UNDERSTANDING A NEW TECHNOLOGY; WHAT'S HARDER IS TO THINK CREATIVELY ABOUT IT.

On November 20, 1917, at the Battle of Cambrai, a new technology was used successfully for the first time. In a plan conceived by a young British staff officer named J. F. C. Fuller, hundreds of tanks advanced on astonished German trenches. The gains of the British Army were soon lost, but within the year Fuller had planned the tank operations at the Battle of Amiens. There, British tanks broke through the German lines and were followed by Allied infantry, who held the ground thus taken. The Battle of Amiens ended the stalemate of trench warfare and led to the end of the First World War.

After the war, through command of an experimental mechanized brigade, in books, and in journalism (often in collaboration with the British military historian Sir Basil Liddell Hart), Fuller urged the British Army to prepare for a different kind of war. Fuller believed that tanks should be used in concentrated formations for their shocking capacity to penetrate the enemy's defenses. But the British General Staff thought tanks should be used in support of infantry—despite the successes at Cambrai and Amiens, where they had led the advances.

Yet if Fuller and Liddell Hart were unappreciated at home, they found an audience abroad in one imaginative officer, Heinz Wilhelm Guderian, who translated their work into German and agitated for the adoption of their ideas by the *Wehrmacht*.

In his autobiography, *Panzer Leader*, Guderian wrote that in 1929, "I became convinced that tanks working on their own or in conjunction with infantry could never achieve decisive importance. ... What was needed were armored divisions which would include the supporting arms needed to allow the tanks to fight with full effect." He got his way: starting in May 1940, Guderian led a German armored corps in its *blitzkrieg* ("lightning war") through the Ardennes forest, a campaign that ended with the fall of France and the evacuation of the British Army at Dunkirk.

Guderian was 51 in 1940, but he had preserved a quality of mind that seems to atrophy in many of us as we grow older: the capacity to be unconfounded by new technologies. Guderian was not merely an enthusiast of the new technology of tanks. He did without resistance what Fuller had unsuccessfully entreated his own generals to do: think creatively about how they might be used.

In "A Technology Surges" *(p. 70)*, David Talbot provides a modern analogue in his account of a new military intelligence network called TIGR (or Tactical Ground Reporting System). Developed by the U.S. Defense Advanced Research Projects Agency, TIGR is a "map-centric application that junior officers can study before going on patrol and add to upon returning." It is part of a broader effort the military calls "network-centric warfare," in which information is swiftly relayed to soldiers. TIGR is popular with junior officers because it allows them to exchange information in a way that recalls the "peer production" common to wikis, rather than relying on whatever information a battalion intelligence officer chooses to disseminate. Yet as John Arquilla, a professor of defense analysis at the Naval Postgraduate School and a leading proponent of network organization in the military, writes on page 12 *("Network Warfare")*, "These technologies are wonders, but generally they have not been accompanied by shifts in military doctrine and organization. ... New organizational forms and practices must develop along with new tools."

For anyone who has invested a lifetime in understanding the uses and benefits of a technology that has become outmoded, it can be supremely hard to think creatively about a new technology. Our difficulty is that we have powerful emotional reasons to dismiss its capacity to disrupt our established ways.

Elsewhere in the magazine Jason Epstein provides a different example of this melancholy truth *("What's Wrong with the Kindle," p. 12)*. Epstein may be the greatest living publisher: at Random House, where he was editorial director for more than 40 years, he invented the modern paperback, and he cofounded the *New York Review of Books* and the Library of America. He is certain there will be no large market for electronic readers like Amazon's Kindle (see one cracked open on page 94). Epstein understands that the digital transmission of books is an established fact, but he believes that "the most rational form of digital transmission is not an electronic reader posing as a book but an actual library-quality paperback that has been printed, bound, and trimmed at low cost on demand, created from a digital file at point of sale by a machine like an ATM." In this, he is like the British generals who understood that the tank was an important new technology, but not that it would change warfare.

How can we stay young? How can we be unconfounded by 2008's "10 Emerging Technologies" *(p. 51)*? Certainly, we must not suspend our critical faculties: not all the scenarios suggested by such technologies are equally plausible, and something of the past always leaks into the future. But we should try to be as little attached to the past as teenagers, and to satisfy our creativity not in the disparagement of new technology but in the contemplation of how it might change our lives. Write and tell me what you think at jason.pontin@technologyreview.com. —*Jason Pontin*

MARK OSTOW

PHOTO COURTESY OF THE MACHINE TOOL MUSEUM

Tools that Create

A short drive through the verdant hills of Basque country from the resort town of San Sebastian, the Machine Tool Museum occupies a rustic open space in the center of the small city of Elgoibar. The museum tells the story of the region's machine tool industry—beginning centuries ago, when ironworkers took advantage of high-quality local ore to create grillwork for cathedrals around Spain, and people began developing machines to shape those pieces. Spain's machine tool sector is now the third largest in the European Union.

From bicycles and guns in the early part of the last century to airplanes and automobiles today, the industry has continued to grow and innovate, propelled by research on how to meet ever-changing consumer needs. This research takes place both within companies and at a network of research centers funded by local companies in partnership with national and local governments.

Nicolás Correa, the top milling machine producer in Europe, sells machines that help shape parts for automobiles, airplanes, and windmill blades.

PHOTOS COURTESY OF NICOLÁS CORREA

Process of Creation

Behind nearly every product in use today are the machines that created it. "Machine tools are enablers of almost everything in the world," says Javier Eguren, managing director of the milling-machine manufacturer Nicolás Correa, who was recently appointed president of the European Committee for Cooperation of the Machine Tool Industries. "They transform prime materials, metals, and other components, to get the shapes needed." Processes such as cutting, stamping, milling, drilling, grinding, and boring all form part of the process that, for example, creates the tools and dies to turn sheets of metal into automobile parts.

Machine tools have gone through a number of technological revolutions. A hundred years ago, many machines in a room were often powered by a single motor that turned an axis that propelled a belt whirring along the ceiling. That belt transferred energy to axles, which in turn transferred it to the machines themselves. A major change was the introduction of machines with their own independent motors. In the 1970s came computer numerical control (CNC), in which machining operations are directed by software. Today the vast majority of machine tools produced in Spain are equipped with CNC.

"That was really the largest change in the industry," says Eguren. "Since then, I'd say the major changes have been through advances in productivity and precision." Machines today are exponentially faster and more precise than those available only 20 years ago.

A number of innovations have made those changes possible. As machines increase in both size and speed, retaining precision remains a challenge. The machines heat up as they work, and this increase in temperature causes metal to expand. "So measuring precisely is one of the big research areas in this industry, to know exactly where you are at all times with your tool," says Eguren. One research goal, he says, is to reduce errors down to the order of only a few microns.

Nicolás Correa has made milling machines for more than 50 years, selling them around the world; it is now the top milling-machine producer in Europe. These machines tend to be geared toward shaping large components, such as dies for shaping the body of a car or the structural components of an airplane. More recently the company has focused more closely on the growing energy sector, creating machines to shape components of windmill blades. It also creates specialized, flexible machines.

To add value to its machines, in 2007 Nicolás Correa spun off a company called GNC Laser, which patented a laser technology that could repair, for example, holes in components caused by a slip in the machining process. This same technology can also harden the surface of dies degraded by the stamping process.

The Danobat companies, which together form one of the largest machine tool corporations in Spain, are world leaders in machines to grind blades used in airplane engine rotors. The Danobat research center, Ideko, focuses exclusively on developing improvements for machine tools.

Fagor Arrasate, a mechanical-press manufacturer and one of the largest machine manufacturers in the region, has taken advantage of improvements in motors to redesign its presses. The company is now able to make larger presses that are flexible enough for customers to quickly change the profile of a piece. It's also developed a high-speed robot that hovers in the narrow spaces above presses and can quickly move pieces between machines.

"We're also developing new systems to reduce the consumption of energy, materials, and oil," says David Chico, product development manager of Koniker, the research center of Fagor Arrasate.

Fagor Automation manufactures solutions for machine-tool automation. Recently the company has improved the precision of the machining process through advances in what are known as encoder systems. In a new building raised only four years ago, the new system determines the

Fagor Automation (above) provides systems that computerize and enhance the precision of machines, while the milling and boring machines from Juaristi (below) allow customized solutions for customers.

PHOTOS COURTESY OF FAGOR AUTOMATION AND JUARISTI

location of products being processed by analyzing light passed and blocked by a series of lines on the scale of only hundredths of a millimeter. The technique involves etching glass and depositing layers of chrome and resins in carefully controlled environments where the temperature, humidity, and level of air particles remain at specifically determined levels. The machine uses the gradated glass to read its position, and then the CNC system adapts the location of all necessary parts of the machine.

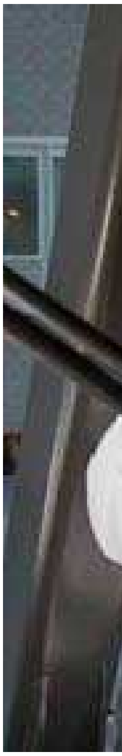
"The accuracy is the most important result," says product and marketing manager J. R. Arriolabengoa. To prevent any vibrations from compromising that accuracy, the company built a literally floating room—a building within a building. There are only two companies in Europe and one in Japan with the facilities to produce gradated glass at this precision for industrial purposes. Fagor Automation has also created a thermal system to prevent any loss of accuracy related to temperature changes in the machine environment.

Meanwhile, improvements in technology such as sensors for vibration, temperature, and location allow companies to develop machines that can more easily correct themselves or notify users of potential problems, on the whole making the machines more user-friendly.

In addition, as customers demand greater flexibility to change the shape of their products more quickly, Spanish companies are focusing on creating custom-made solutions, rather than specific tools that conduct a single operation. Etxe-tar focuses on specialized, flexible machines that are developed with the specific customer in mind. Juaristi, a maker of milling and boring machines, has created systems that allow companies to carry out different processes with the same machine.

Many of these machine tool businesses reach outside Spain for the bulk of their income; export markets for Spanish companies grew approximately 30 percent in 2005 and 2006. Nicolás Correa exports about 85 percent of its products, and Etxe-tar sells crankshaft machines extensively to car companies in the United States.

"The end-user sectors are completely globalized," says Xabier Ortueta, director of the Machine Tool Manufacturers Association of Spain. "We sell in many different markets, where the production is based. For the last five years, production of many industrial products has moved to China, India, and Eastern Europe, so we move with our clients."



Environmentally Conscious

One of the most significant changes in the industry today is the heightened concern about environmental impact. In fact, new environmental standards might be considered the next stage of the industrial revolution.

As consumers seek out environmentally sustainable products, and as companies strive to reduce their impact on climate change, the machinery industry is working to meet those demands. Innovations include machines produced with less material and electricity, machines that require less electricity to operate, and machines that can use smaller amounts of lubricants and coolants in more environmentally friendly formulations. Juan José Miguel, marketing director of Etxe-tar, says the company's machines now use significantly less coolant.

The Spanish machine tool sector has taken a leading role in developing eco-friendlier machines, assisted by advances in related technologies. "New technology permits us to design machines and check the design through simulations," says Nicolás Correa's Javier Eguren. "We can be far more precise and avoid overbuilding the machines, which we did in the past to ensure rigidity and safety."

To meet international environmental standards, both the automotive and aerospace industries have been introducing new, lighter materials, including concrete or carbon fiber in place of some steel components. Carbon fiber, a composite, is especially important as a replacement for aluminum in the aerospace industry. The company MTorres, located in Pamplona, anticipated those changes in the aerospace industry and developed machinery to work with this material.

"Usually a machine places strips of material on a mold with the shape of the part that is going to be manufactured," explains Luis Izco, managing director of MTorres's aeronautics division. "The problem is that the current systems are relatively expensive, and the productivity you can get is relatively low." A cheaper and more rapid production technique is not as effective for complex shapes.

The company has developed a system that places the material on a given shape that can "make the cuts and restart on the fly," Izco continues. "With this, what you are getting is a very high deposition rate, and the number of kilograms per hour on this system is much higher than [in] conventional systems." This system also allows placement on complex shapes and parts. The first machine has been ordered by a company providing parts to the Boeing 787 and is expected to be delivered within a year.

Centered Research

In their quest for improvements and new products, companies can draw on a network of research centers that stretches around the country. These centers receive a certain amount of ongoing funding from the national government and from regional authorities, and they raise the rest of the necessary funds from specific program grants and from the companies with which they set up agreements.

About an hour outside of Barcelona, in the heart of Catalonia, the Technological Center of Manresa (CTM) focuses on materials science and the development of new materials. It opened its labs and research facilities only five years ago but has already played a key role in a number of projects. (See Focus on an Innovator for a highlight of one CTM partnership.)

One of the center's most important projects is its work with Forma 0, the government-funded research collaboration begun in 2006 that looks to adapt materials and manufacturing processes to take advantage of new high-strength steels. These tough steels have a particularly high level of a characteristic called springback, which makes them very challenging to tool.

The Spanish automobile company SEAT heads some of the lines of investigation in this consortium. "These new materials allow us to reduce weight in our products, and thereby reduce fuel consumption, while improving our crash performance," says Andre Koropp, SEAT's business manager. "We'd like to use more and more of these materials for our products, so we have to prepare our manufacturing processes to be able to employ them." The research primarily involves developing new tools and dies, particularly to optimize the hot-stamping process that is most effective with the high-strength steels.

A number of labs at CTM are devoted to teasing out different aspects of hot-stamping's effects on machine materials. "Each material behaves differently," says José Manuel Prado, director of CTM. "You need good material models to have a reliable simulation of what will happen in any given situation. One of our stronger points here is

PHOTOS COURTESY OF FATRONIK

to simulate those industrial processes." The research focuses not only on increasing the effectiveness of hot-stamping but also on finding ways to form the steel cold, despite its strength and resistance.

"It's quite difficult to predict the material's springback—it depends on the strength and thickness of the material, on the friction between the part and the tool," Prado continues. "All of this is so far an unresolved problem." And it's one that the labs are working to solve. In addition to the modeling, another project involves using physical vapor deposition to apply extremely thin coatings that increase the hardness of tools. This research has led to a spinoff project investigating decorative applications, such as jewelry or home goods covered with a deposited layer of titanium that shines like gold.

In San Sebastian, renowned for its boulevards and Michelin-starred restaurants, the research center Fatronik focuses on technologies that will have industrial market applications, such as artificial-intelligence and communication systems that integrate a variety of sensors into machines. The center has paired with companies such as MTorres to increase flexibility in big machines. It's also developing robots to assist in the manufacturing process, including a crawling robot—along the lines of a giant spider—that could, for example, drill on complex surfaces such as aeronautic wings. Such robots could speed up some functions that now depend on significantly slower manual labor.

As a way to ease robots into a number of conservative sectors, Fatronik is also working on mobile robotic platforms, a technology geared toward keeping the robot moving and not bumping into objects. Instead of using sensors to detect obstacles, the robot uses lasers, ultrasound, and a ring of infrared lights to constantly search for open spaces that it can move into. This is a relatively low-cost solution that could be used in conjunction with other industrial applications—for example, to increase safety on forklifts.

A third industrial-robotics project at Fatronik involves Spain's well-known food industry. Designed in cooperation with a research center in France, a new, patented system is one of the fastest in the world for what's known as pick-and-place

"New technology permits us to design machines and check the design through simulations. We can be far more precise and avoid overbuilding the machines, which we did in the past to ensure rigidity and safety."

tasks. The robot can stretch its long arms down to pick up a food product from one location and place it in a second at the rate of 240 cycles per minute. In one rather unusual application employed close to home in the Basque region, the robot is now being used to determine the sex of fish. The robot's arm inserts a needle into the stomach of a fish, shoots a light beam through the needle, and determines from the refraction of the light whether the fish is male or female. Females are then separated out for caviar.

(continued on page S7)

PHOTOS COURTESY OF FATRONIK

Focus on an Innovator

About a half-hour outside of Barcelona, a small family company has developed a new material that may help the automobile industry reduce car weight and fuel consumption.

Rovalma originated as an import business in the 1970s, supplying materials such as tool steels for dies and molds. Isaac Valls, son of the company's founder, left Spain to study for his PhD in materials science at Stanford University. During his first year, in 2000, he stayed up to date on the company. "I was taking my time, taking classes in everything that interested me," he says. "All of a sudden I detected that the industry was going to need new tool steels in three to four years." He sped through his second year in three months and returned to Spain.

The big change that Valls observed in the industry was the introduction of advanced high-strength steels. These new alloys provide a number of benefits over traditional steel alloys. Because they are so much stronger, they allow manufacturers to use less material even as they make cars safer. The resulting weight reductions can improve gas mileage and decrease a car's impact on climate change. But their extreme strength also makes these materials difficult to shape.

The high-strength steels, Valls predicted, would rapidly wear down cutting and shaping tools. "We thought that the tool material the industry has been using for the last 40 years is not going to hold up," he says. His predictions proved accurate: suddenly tools that had lasted for hundreds of thousands of pieces shattered after only 100.

With more enthusiasm than resources or equipment ("we only had one little optical microscope and nothing else," he recalls), Valls started researching alternatives. Fortunately, the research center CTM had recently opened in Manresa, not far from his family's business. In addition, the Spanish government had recently increased available research funds.

Valls began investigating what caused the failures. With the help of CTM, he determined that the cracks originated in the carbides, compounds produced by heating the tool steels to achieve the required resistance. CTM provided the equipment and a researcher able to assist in nano-indentation, using a diamond tip to create the beginnings of cracks and determine the fracture toughness of different carbides.

The key, he realized, would be a tool steel with tougher carbides, so he developed a new alloy. Selling it proved to be the next challenge, as car companies looked to their usual suppliers for solutions. "We were like a tiny mosquito or even a bacteria compared to our competitors," says Valls. "They'd been there for a hundred years—they had the market power, they had everything." But not, it turns out, the right product. Desperate to increase production speeds, automotive companies finally turned to this family-owned Spanish business. Today the new tool steel is the company's top seller.


Isaac Valls, owner and head of research at Rovalma

Then Volkswagen decided to implement hot-stamping, a process in which the new steels would be formed at a temperature high enough for the structure to change and become more malleable. Says Valls, "This is the newest technology in the shaping of sheet metal, and they were the first European company to implement it in-house."

Volkswagen was pleased by Valls's previous work, as the first die made from the company's new tool steel had already finished 800,000 pieces. The company asked him to find a solution to the problems that arose in hot-stamping. The material needed to be cooled down rapidly to maintain its form and attain the necessary hardness. Volkswagen had already changed the entire production line, installing furnaces, robots equipped to work with hot materials, and cooling systems. It came to Valls with one question: will this new process degrade the die?

After some testing, Valls reported that the dies would survive, but the painfully slow process meant the final product remained expensive. "You're getting two pieces per minute," he told Volkswagen, "and your competitors are getting maybe one. What if we produce a tool steel that can produce six or eight pieces a minute?" Volkswagen executives, he says, told him they only dreamed about reaching those numbers.

Valls partnered again with CTM. He saw that the impediment was the tool steel itself, the time necessary to transfer the heat from the high-strength steel through the die into the cooling system.

"Everyone had tried for the last hundred years to increase the thermal conductivity of hot work-tool steels," says Valls. No one had succeeded. "But my approach was totally different. I was approaching it from the fundamentals." Relying on the understanding of quantum mechanics that he'd gained at Stanford, and taking advantage of basic research conducted by other researchers (but not on tool steels), he investigated both the steel's ceramic phase and its metallic phase. He realized that one element in the alloy was compromising its conductivity. Valls created a new alloy without this element, but he needed to test it in a lab in Germany.

The lab was busy. Three weeks later, his nervousness at a fever pitch, he opened his mailbox. "I started screaming so loudly that the neighbors came out," Valls recalls with a laugh. "I said, 'You're all invited to dinner!'" The new alloy nearly tripled the best existing conductivity in tool steels. The potential productivity of Volkswagen's hot-forming process quadrupled, and the company signed a two-year exclusivity contract with Rovalma that expires in September.

Valls appreciates that the contract with Volkswagen allowed him time to prepare for the demand that will greet him after the contract expires. In addition to the factory in Spain, he's opening one in Germany. Though Valls is in no hurry to broaden applications past the automotive industry at this time, he says the aerospace industry has already expressed interest in working with Rovalma to increase productivity as well.

"Traditionally, foods were processed by thermal methods to make them safer for longer. But the heat has an impact on the quality of the foods and the integrity of the ingredients."

Into the Kitchen

Fatronik joins other companies and research centers in taking advantage of Spain's culinary acclaim. Spanish food machinery companies supply not only the Spanish market but the global one, garnering fans as they continue innovating to meet consumer needs.

One factor driving innovation has been the change in the way people eat. "Family meals have been reduced, at best, to once a day, and that's dinner," says Josep Monfort, director of food technology at the Food and Agriculture Research and Technology Center (IRTA in Spanish). "And the average time dedicated by the whole family to that meal is about 20 to 35 minutes. Companies need to adapt to the new needs and attitudes of consumers. Ready-to-heat, ready-to-eat—those types of foods are growing in the market."

IRTA, located in a rural area near Girona, opened in 1985 with funding from the government and local businesses. Its spare white halls and cavernous rooms house machinery and labs to test different aspects of food production. In one, a huge x-ray machine allows the center to perform noninvasive tests on animals for genetics companies. Another series of rooms provides the means to evaluate drying methods. The natural light flooding the space feels cold, and it is: heat is removed from the light so as not to affect any of the heat-sensitive research.

Monfort cooperates with food processing companies in the area to create new technologies. In a recent successful collaboration, researchers at the center worked with the local company Metalquimia, which produces machinery for meat processing, to develop a new system that could vastly increase productivity in meat curing.

Josep Lagares, whose father founded Metalquimia, explains that the current system of curing and drying meat for products such as chorizo and salami hasn't changed significantly since the time of the Romans. The ground meat is salted and infused with spices. It ferments for a short time to fuse the mass together. Then the meat hangs and slowly dries before the final product is ready to be sold.

Today, though, many people around the world buy meat pre-sliced, instead of whole. "So why don't we turn the process around? Why don't we slice it first and then dry it?" continues Lagares. "If you pre-slice the produce, you have a much smaller surface to dry."

Metalquimia partnered with IRTA and a local meat processor. For three years, the company has been perfecting the machinery to optimize the taste, safety, and stability of the system. "Unless you're an expert, a professional in the field, the taste is almost indistinguishable [from the standard]," he says.

The company has a small industrial machine at the factory and is putting the finishing touches on a large-scale machine that will be tested at the nearby meat producer. Once Metalquimia is fully satisfied with the results of scaling up the system, it will market the machine to its international customers, many of whom are already clamoring to buy one.

Lagares says the company's creativity began with his father, who invented machines that "simply didn't exist before." For instance, he developed a machine that would inject the meat with brine, allowing for even distribution and curing. Encouraging this type of innovation has become a systematic part of company culture.

Rather than taking advantage of the trend toward increasingly fast food, NC Hyperbaric profits from the growing interest in natural, minimally processed foods. A spinoff of Nicolás Correa, the company began operations in 2000, industrializing a heat-free pasteurization method.

"Traditionally, foods were processed by thermal methods to make them safer for

NC Hyperbaric's high-pressure chambers pasteurize food without heat.

PHOTOS COURTESY OF NC HYBERBARIC

longer," says technical sales manager Francisco Purroy. "But the heat has an impact on the quality of the foods and the integrity of the ingredients."

The new technique involves using extraordinarily high levels of water pressure to disrupt the normal functioning of bacterial cells. This process has been known since the late 1800s, but the technology has not been available to implement it on an industrial scale. In NC Hyperbaric's machine, food in well-sealed flexible packaging is loaded into a cylinder. Then the chamber fills with water. After the chamber has been filled, more water is pumped in, increasing the pressure. "It's like taking the final packaging and putting it very deep in the ocean—even deeper than the pressure you could find in nature," says Purroy. This pressure destroys molecular bonds in microorganisms but not the nutrients in food or the molecules that confer its distinctive flavor. The final product retains more of the fresh taste and the original nutrients than food treated with heat, Purroy says.

Improvements in steel and other materials have made it possible to scale this process up from the laboratory. One key part of the design involves tightly wrapping miles of wire around the chamber to compress the steel. Under high pressure the precompressed steel is actually in a relatively relaxed phase, which helps the vessel last longer. The company patented its designs and continues to dedicate 10 percent of its turnover to research each year. So far, only two companies are marketing this type of technology industrially, with NC Hyperbaric leading the way.

Many customers have been able to use the technology for purposes other than simple pasteurization. Seafood companies in Mississippi and Japan use the pressure to pop open bivalves such as oysters and mussels without the arduous manual labor usually required. Another seafood application involves lobsters: because their meat typically cannot be extracted without cooking, chefs who want to use lobster usually buy the meat already cooked or cook it themselves, so that it's been cooked twice by the time the dish is served. The new process makes it possible to detach the raw meat from the exoskeleton. The first companies began using this pressure machinery to extract raw lobster meat in 2005, and the product is already popular with chefs.

Opening the door to still more new products, a dairy multinational in New Zealand is using the hyperbaric chamber to pasteurize vitamin-rich colostrum, the first milk mammals produce, which cannot be treated thermally. This product is being marketed in China, where it is associated with good health.

Other manufacturers of food packaging machinery have also been able to innovate and expand in recent years. Posimat, which makes machines for filling bottles, patented a system that can automatically change from one size of bottle to another. Mespack, whose machines utilize flexible packaging, developed a system to allow the machine to automatically correct for unexpected stretching in a given material.

Ulma Packaging creates a wide variety of automatic machines and packaging technologies, from thermoforming to bagging with stretch- or shrink-film machines to sealing plastic films. Working closely with customers to develop the appropriate solutions, the company has focused on researching new films and implementing advances in 3-D design workflow, robotics, and communication or electronic controls.

"We have to stay very closely connected to film manufacturers because of innovative solutions coming in films themselves," says Francisco Etxaniz, managing director of Ulma Packaging's research center. Here, too, environmental concerns are driving innovations. As companies meet demands to recycle more and produce less waste, new biofilms are being developed that are thinner, less toxic, and biodegradable. "We've developed and patented technologies to deal with the properties of these thinner films," says Etxaniz.

As consumer products advance and trends such as concern about environmental impact evolve, Spanish companies will continue to develop new technologies to meet these ever-changing needs.

Resources

ICEX (Spanish Institute for Foreign Trade)
www.us.spainbusiness.com

Machine Tool Manufacturers Association of Spain
www.afm.es

Nicolás Correa
www.correaanayak.es

Juaristi
www.juaristi.com

Fagor
www.fagor-automation.com
www.fagorarrasate.com

Grupo Danobat
www.danobatgroup.com

Etxe-tar
www.etxe-tar.com

Rovalma
www.rovalma.com

Metalquimia
www.metalquimia.com

NC Hyperbaric
www.nchyperbaric.com

To find out more about New Technologies in Spain, visit:
www.technologyreview.com/spain/machinery

For more information visit:
www.spainbusiness.com

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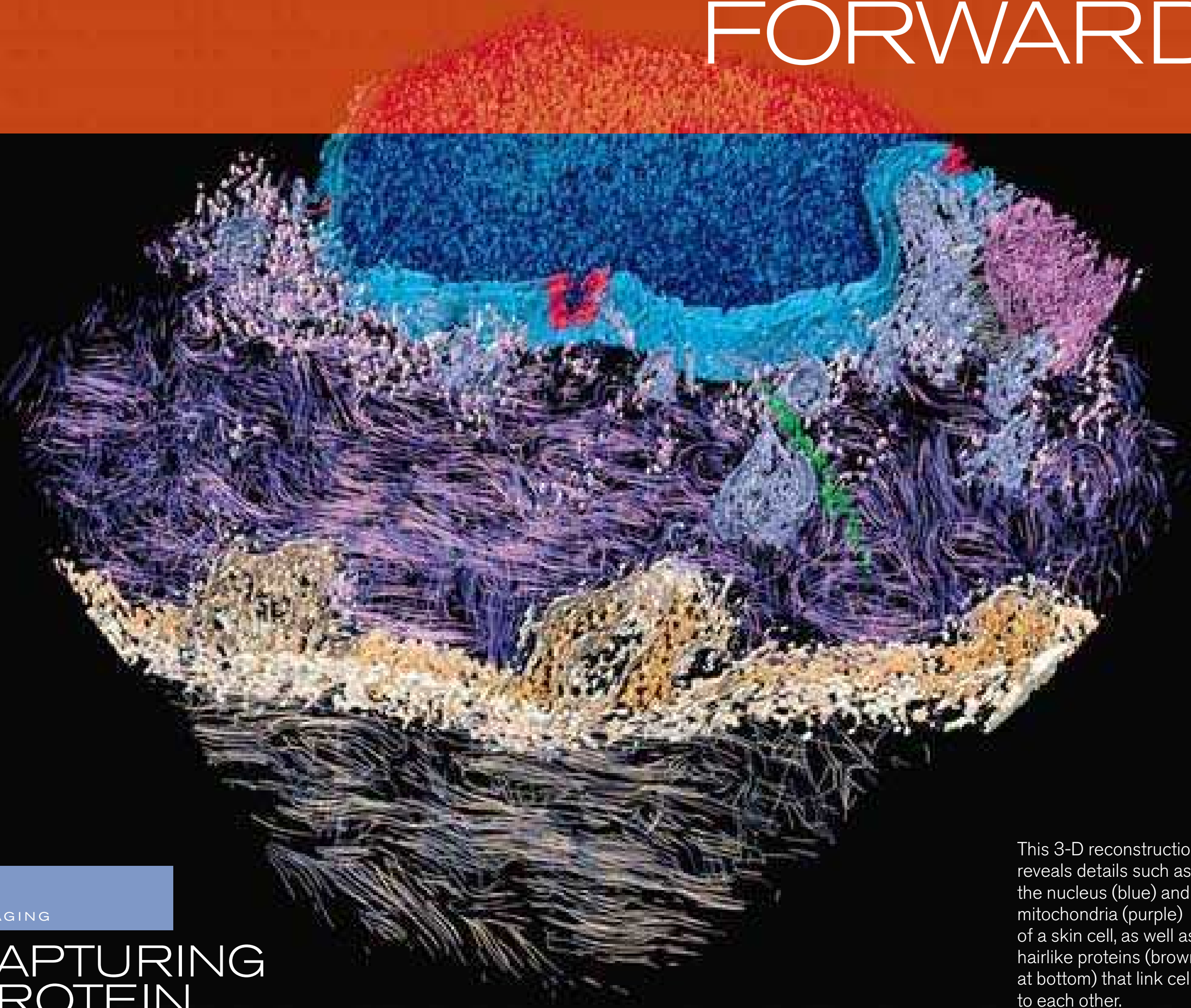


This 3-D reconstruction reveals details such as the nucleus (blue) and mitochondria (purple) of a skin cell, as well as hairlike proteins (brown, at bottom) that link cells to each other.

IMAGING

CAPTURING PROTEIN INTERACTIONS

Freezing and slicing gives a snapshot of life inside cells

SCIENTISTS CAN now see how proteins organize and interact, thanks to the technology that created this image of skin tissue. The technique reveals the structure of proteins and the relationships among them in unprecedented detail, providing information that's vital for understanding disease and cell functions. "When you see the proteins, you immediately also see ... how they interact in an undisturbed environment," says Achilleas Frangakis, the biologist who led the research at the European Molecular Biology Laboratory in Heidelberg, Germany. "At this resolution, the cell is essentially an uncharted territory."

The research group froze cells to –193 °C by plunging them into liquid nitrogen, sliced them into 50-nanometer-thick sections, and illuminated the slices with a beam of electrons. Software refined the resulting electron tomography images into virtual slices that were even thinner—as little as half a nanometer thick. Combinations of such slices enable 3-D viewing, too.

The imaging technique, called cryo-electron tomography, had previously been used on smaller, simpler cells, such as bacteria. But coupled with the slicing technique, cryosectioning, it can work on almost any cell and is "truly a first," says Grant Jensen, a biologist at Caltech who specializes in cryo-electron tomography. *—Jocelyn Rice*

ACHILLEAS FRANGAKIS, EMBL

MATERIALS

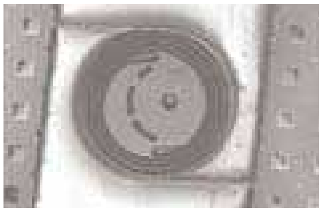
EXPANDABLE SILICON

A new chip design could lead to far cheaper large-area electronics

THE SEMICONDUCTOR industry is great at miniaturizing silicon devices and packing huge numbers of them into very small spaces. But for some applications, such as big-screen displays, it's helpful if transistors and other silicon-based devices are distributed relatively sparsely across many centimeters or even meters. Traditionally, cheap methods for distributing electronics over large areas have produced low-performance devices; improving performance has required lots of expensive silicon.

Now Peter Peumans, a professor of electrical engineering at Stanford University, and his colleagues have developed small silicon chips that can be mechanically expanded to cover large areas, including curved surfaces such as the one pictured below. The chips consist of discs of silicon with silicon wire spooled around them. Each disc can incorporate transistors, pressure sensors, or tiny solar cells. When the corners of the chip are pulled, the wires coiled around the silicon discs unwind. As they do, the discs, which start out nearly touching each other, spread apart. The result is a netlike array of silicon devices.

Peumans is working with Boeing to put crack-detecting sensors between layers of structural composite materials on aircraft. And he founded NetCrystal in Mountain View, CA, to make photovoltaic panels that spread out islands of photovoltaic chips in a way that exposes them to more sunlight, without the need for focusing lenses or mirrors. What's more, distributed high-performance transistors could control pixels in next-generation displays, such as those based on organic light-emitting diodes. *—Kevin Bullis*



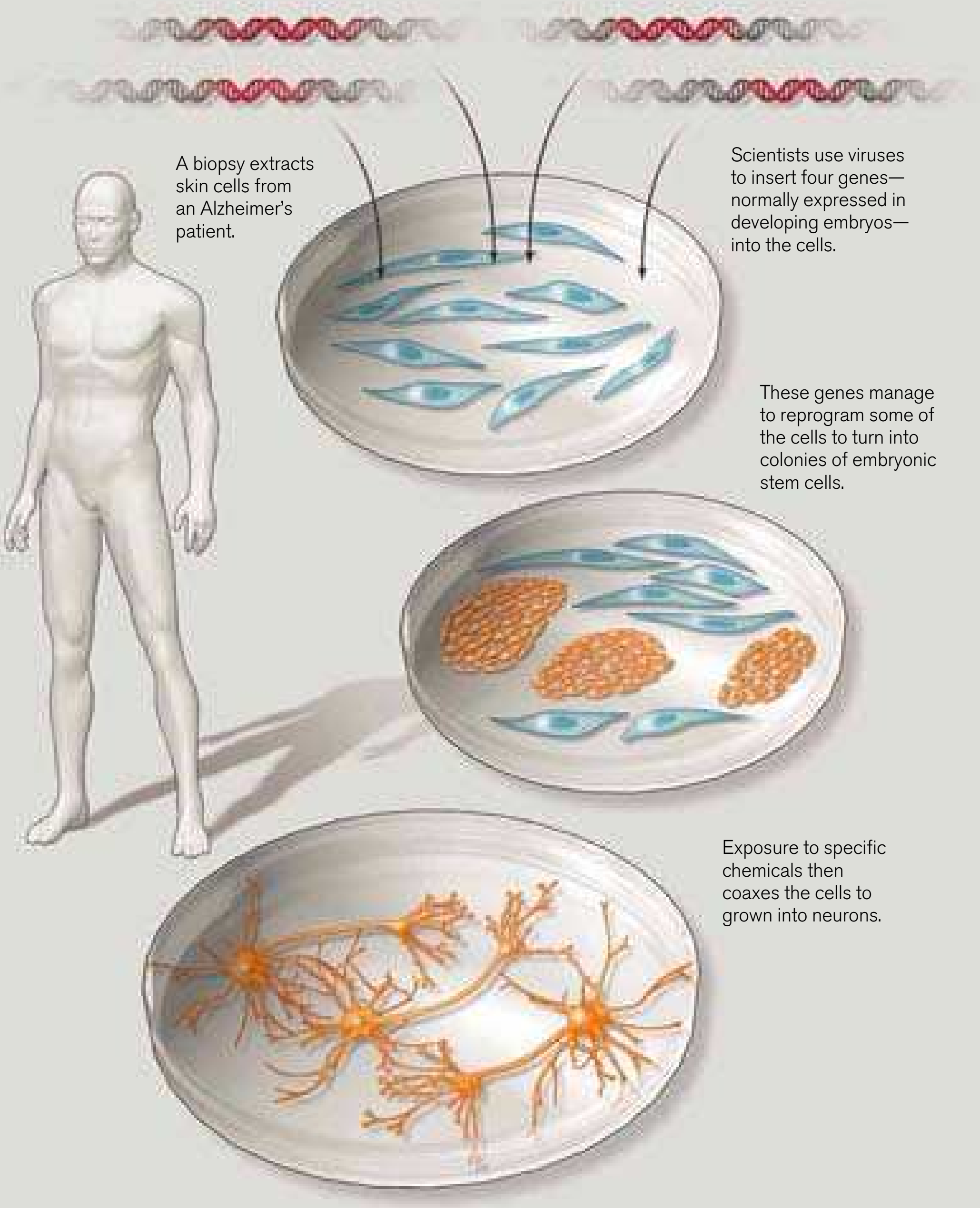
An array of silicon discs (dots on slide, bottom left) is expanded (bottom right) in a laboratory setup. Such arrays can expand to as much as 50 times their original area and be molded to curved surfaces for applications such as structural sensing. An individual 200-micrometer-wide disc (above, top) is surrounded by a coil of wire that unwinds when the array is expanded (above, bottom).

JONATHAN SPRAGUE; INSET: KEVIN HUANG

BIOTECH

CUSTOMIZED STEM CELLS

Reprogramming cells taken from disease sufferers could lead to new treatments



THE DISCOVERY late last year of a way to generate stem cells from adult skin cells could allow scientists to study disease in unprecedented detail, from earliest inception to final biochemical demise. That's because the stem cells could be used to develop cell lines derived from people with a given disease—neurons from Alzheimer's patients, for example, or blood cells from people with sickle-cell anemia. The resulting trove of cells would capture all the genetic quirks of these complex diseases.

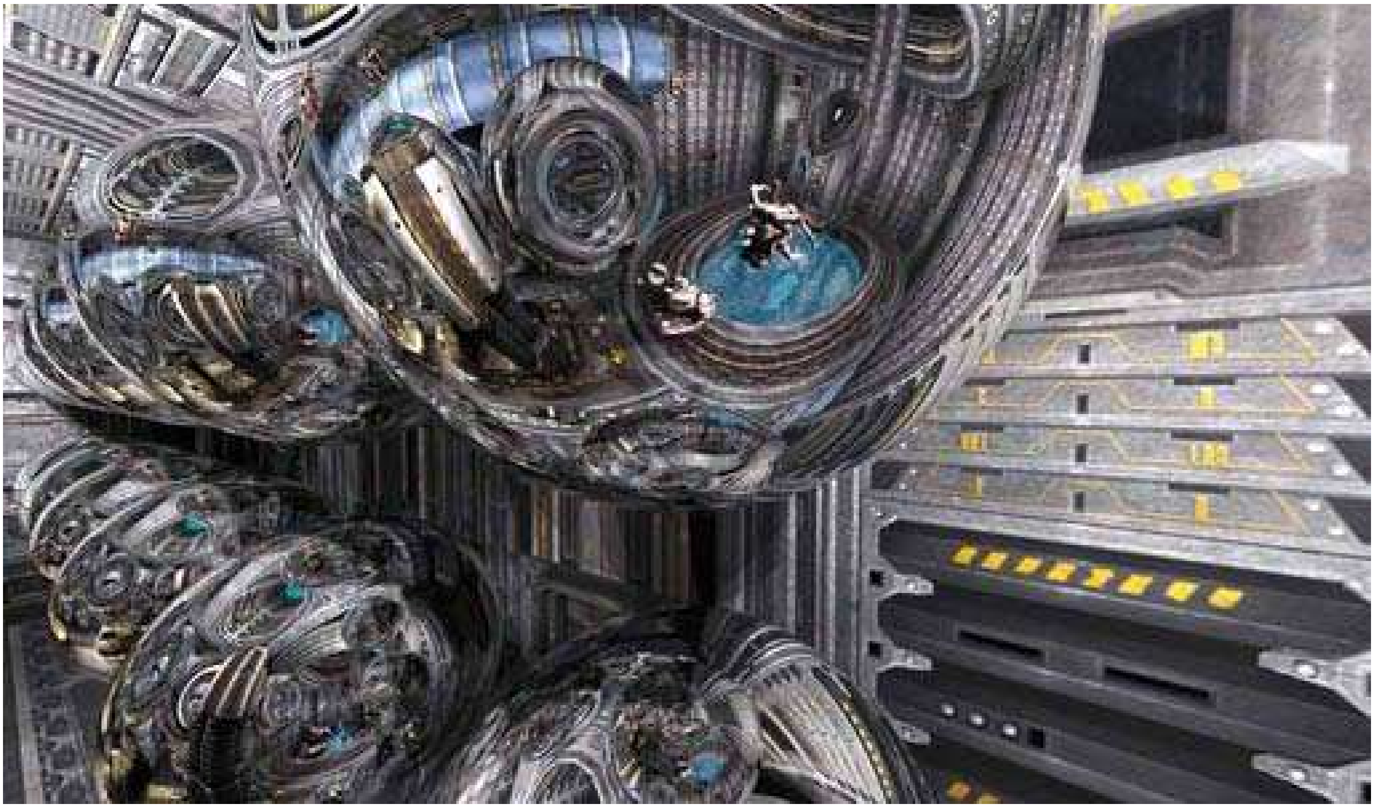
By comparing the development and behavior of cells derived from healthy and diseased people, scientists could determine how disease unfolds at a cellular level, identifying points in the process where intervention might do some good. They could also use the cells to test drugs that might correct biochemical abnormalities. "We want to use these cells to ask and answer questions that can't be asked and answered any other way," says M. William Lensch, a scientist at the Harvard Stem Cell Institute.

Lensch and collaborators in George Daley's lab at Children's Hospital in Boston are attempting to create stem-cell lines using tissue samples collected from people with Huntington's disease, sickle-cell anemia, and another blood disease called Fanconi anemia. Other scientists are expected to follow suit, investigating other diseases. —*Emily Singer*

LIKELY RESEARCH TARGETS

Cell Type	Disease	U.S. sufferers
Motor neurons	ALS	30,000
Dopamine neurons	Parkinson's	500,000
Red blood cells	Sickle-cell anemia	70,000
Muscle cells	Muscular dystrophy	250,000
Pancreatic cells	Type 1 diabetes	100,000 to 200,000

TAMI TOLPA



SOFTWARE

REAL-TIME REFLECTIONS

New algorithms promise dramatically improved animation

ONE OF THE toughest computing tasks in animation—for games, movies, or even medical imaging—is also one of the most important for realism: accurately rendering reflections and shadows. But today's best mass-market software only approximates the play of light. Now researchers at companies like Adobe and Intel are developing software that can, almost in real time, change the appearance of moving objects as they pass through shadow or reflect new aspects of their surroundings. In effect, the software determines what path the light in the scene would have taken to reach each pixel. If it identifies a reflective surface or an obstruction, it changes the pixel's color value accordingly. The technology can handle multiple shadows and reflections—even reflections of reflections. Earlier versions, which took hours to execute these steps, were used mainly by architects and Hollywood animation studios. Daniel Pohl, an Intel researcher, says the technology needs fine-tuning, but he thinks that future personal computers with multiple processing cores could use it for everything from traversing virtual worlds like Second Life to viewing 3-D medical images. The software could reach consumers within five years. —*Kate Greene*

TRACKING REFLECTIONS
These images—of a scene Intel researchers adapted from the video game Quake 4—illustrate a technique called real-time ray tracing. Reflection pathways are depicted in colors. Red (left) indicates the raw image. The first set of reflections (center) is in green; blue (right) indicates reflections of reflections. The final image (top) is enriched by many reflections.

COURTESY OF INTEL, ID SOFTWARE, OPENRT

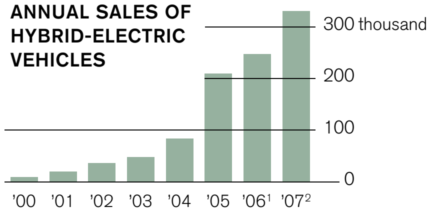
ENERGY

PLUG-IN HYBRIDS: TAILPIPES VS. SMOKESTACKS

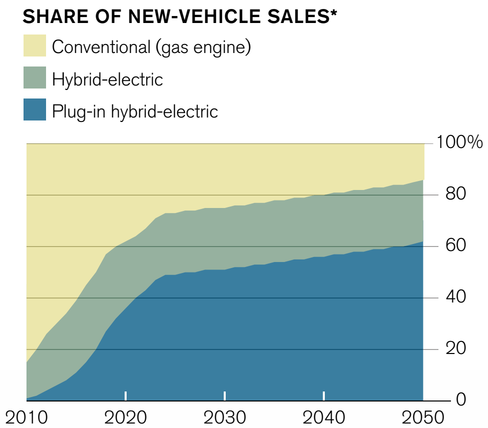
Plug-in hybrids may one day constitute a majority of the cars on U.S. roads. Like today's hybrids, they have both a gasoline engine and an electric-drive motor whose batteries can be recharged by the engine. But they can also be recharged at a standard wall socket. Given that they'll raise electricity demand and increase power-plant emissions, will they really reduce overall greenhouse-gas production? It turns out that plug-ins always result in lower emissions than conventional cars do, and they beat regular hybrids handily—except when the electricity comes from coal (the source of 43 percent of U.S. electricity), according to a study. But as gasoline comes from dirtier oil sources, such as tar sands, plug-ins may win even when powered indirectly by coal, one study author says. —*David Talbot*

HYBRIDS ON THE RISE

Sales of hybrids like Toyota's Prius are surging ...



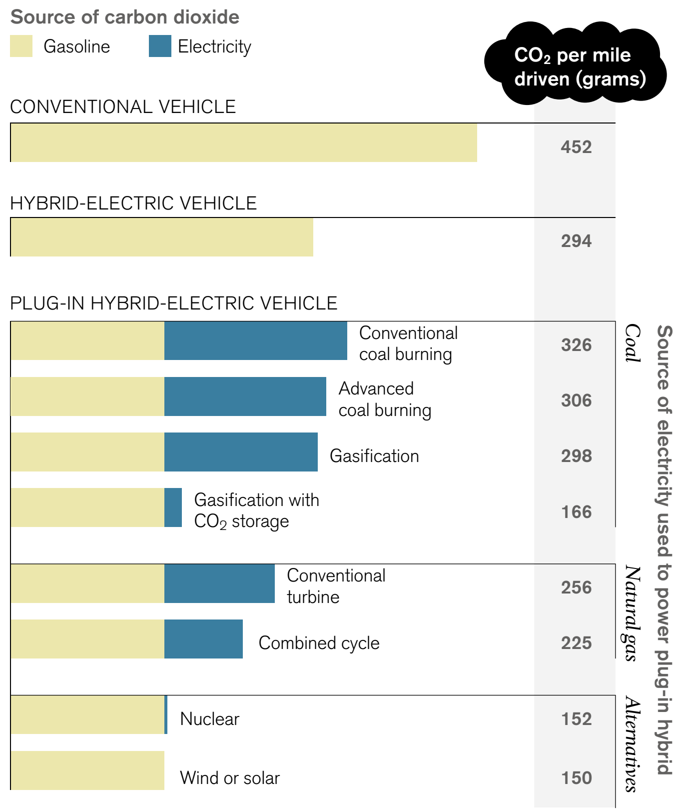
... and plug-ins are expected to reach market soon. They could dominate after a few decades.



GM's Chevy Volt concept car

PLUG-INS: EMISSION COMPARISON

The chart below shows total carbon dioxide emissions when different energy sources are used to power a light-duty sedan. The totals, which are based on projections for 2010, include emissions from the mining and transport of coal, oil, or uranium (for nuclear power) and the transmission and storage of electricity.



*1. Incomplete data. 2. Partial-year sales figures. *Median projection*
Sources: Comparisons and projections: Electric Power Research Institute and Natural Resources Defense Council (www.epri-reports.org); Hybrid sales figures: Electric Drive Transportation Association

INFOGRAPHIC BY TOMMY MCCALL; CAR CULTURE/CORBIS (VOLT)

Ray Stata, Priti Chatter, Rohit Goyal, and Mukesh Chatter

STARTUP

BIDDING FOR INTEREST RATES

NeoSaej's algorithms could change the rules of online auctioning

NEOSAEJ of Burlington, MA, has developed a novel online auction strategy that it says should produce better interest rates for bank depositors. Its proprietary algorithms allow online vendors to engage in sophisticated behind-the-scenes bidding against each other before their offers are presented to customers.

Let's say you want to deposit $20,000 in a six-month CD. You enter that request at NeoSaej's website. Members of NeoSaej's network of participating banks make bids that suit their business objectives—to raise money quickly, say, or to sell certain products. Before the customer sees these bids, NeoSaej sends the best ones back to the network for counteroffers. The process continues automatically, producing progressively better bids until one bank is left offering the best rate. The company will initially apply the system to CDs and high-yield savings accounts but expects to expand into loans.

Mukesh Chatter, the company's CEO, says the process is far more efficient than today's online marketing. Banks now pay heavily for advertising on search-engine and content-aggregation sites, but only 1 to 2 percent of people who navigate to a bank's website deposit or borrow money. It ends up costing a bank between $400 and $1,000 to attract each new customer online, Chatter says. Such costs are reflected in lower interest rates for savings accounts and higher interest rates on loans.

NeoSaej, which plans to launch this spring (and whose cryptic name Chatter did not explain), says it makes money by collecting a small fee—"substantially smaller" than banks' current marketing costs, Chatter says—on every completed transaction. "Our business model is that if we succeed, then we get paid," he says. That's the same business model used by the online-auction giant eBay. But NeoSaej's process fundamentally differs from eBay's because the "seller," in this case a bank, is continually adjusting its terms to suit business objectives, to beat competitors, and to respond to the market. It's also different from Priceline's model, in which customers name a price and promise to buy from any company that matches it: NeoSaej customers won't have to commit to making a purchase before learning the best rate.

NeoSaej is focusing on banking in part because federal deposit insurance eases a customer's need to research sellers, but the company hopes to move into other forms of commerce. Robert Freund, a professor of management science at MIT's Sloan School who sits on NeoSaej's advisory board, says the company's technology "has the potential to change the way business is conducted on the Internet." —*Erica Naone*

NEOSAEJ

URL: www.neosaej.com

Location: Burlington, MA

Product: MoneyAisle.com

Founders: Mukesh Chatter, founder of Nexabit Networks; Priti Chatter, cofounder of Nexabit Networks; Rohit Goyal, former director of engineering at Enterasys Networks; Ray Stata, founder and chair of Analog Devices

CEO: Mukesh Chatter

Number of employees: 25

Funding amount: $3.5 million

Funders: Gorham Savings Bank, MBPP LLC, NeoNet LLC, Stata Venture Partners II

Partners: Not disclosed

CHRISTOPHER CHURCHILL

Careers in Motion

The Path to Success

Do you want to take the next step toward professional growth? In each issue, Career Resources brings you success stories from executives who continued their education, essential advice from experts on how to achieve your career goals, and a directory of programs designed specifically for the working professional.

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Career Growth Profile

Humayun Arif has been instrumental in reshaping NASA for the next 30 years of space communication. He has played a key role in positioning Cisco Systems as the recognized industry collaborator in NASA's $104 billion Constellation Program to return humans to the moon and to Mars.

This past January, Arif embarked on yet another challenging mission: earning an executive MBA degree from Northwestern University's Kellogg School of Management. Never mind that he's a recognized expert in his field. Never mind that he's 53 years old and has more than 20 years' experience. Arif says he's in need of some education.

"Over the last few years, it has been readily obvious to me while interacting with Cisco's business units that there is strong interdependence of technical decision-making with business economics. One cannot be performed without the other," says Arif, who is a space initiatives manager for U.S. civil programs with Cisco Systems' Global Government Solutions Group. "The value of an MBA ... has clearly become evident."

Arif also admits that he is pursuing an executive MBA degree because his leadership skills could use some reinforcement—particularly in formulating strategies, solving problems, and making decisions in a team environment.

Humayun Arif

Age: 53
Job Title: Space Initiatives Manager, Global Government Solutions Group
Employer: Cisco Systems, Inc.
Program: MBA, Executive Program, Kellogg School of Management, Northwestern University

To read more about how Humayun plans to put his MBA to use, visit
www.technologyreview.com/resources/career/

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MITSloan MANAGEMENT

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To list your program or recruitment ad in our Career Resources section, e-mail Maureen Elmaleh at maureen.elmaleh@technologyreview.com or call 303-975-6381.

BRUCE PETERSON

INTERFACES

LONGHAND GOES DIGITAL

THE LIVESCRIBE Pulse Smartpen turns a sheet of paper into a computer interface. Write down an equation, and the solution appears on the pen's screen. The pen also has a built-in audio recorder: record a lecture, and by tapping the pen on a line from a page of handwritten notes, you can call up the corresponding section of the recording. The pen's computational features work so long as the user writes on paper printed with a special pattern, which is read by cameras in the pen's tip.

Product: Pulse Smartpen
Cost: $149 with one gigabyte of memory; $199 with two gigabytes
Source: www.livescribe.com
Company: Livescribe

POWER SUPPLIES

WIRELESS DEVICE CHARGER

A METAL PAD that wirelessly recharges gadgets laid on top of it stands to eliminate the annoyance of charger cables. Each gadget must be fitted with an adapter that plugs into its battery compartment; metal contacts on the adapter draw power through conductive metal strips on the pad. Adapters are currently available for the Motorola Razr, the BlackBerry, and several Apple products, with more to follow.

Product: WildCharger **Cost:** $59.95; $30 to $40 per adapter, depending on the device **Source:** www.wildcharge.com **Company:** WildCharge

OPERATING SYSTEMS

Instant-On Computing

SOMETIMES you want to send a quick e-mail or look something up online but don't feel like waiting for your computer to boot up. With Splashtop, you can be surfing the Web in seconds. Built into a computer's basic input-output system—the software that sets up the operating system—Splashtop gives you a choice at startup: you can either boot up normally or load a stripped-down operating system that runs just a few common applications. Circuit boards featuring the system are on the market now; they should turn up in computers within months.

Product: Splashtop instant-on desktop
Cost: Circuit board manufacturers generally pay less than $5 per software license, depending on volume and configuration
Source: www.splashtop.com
Company: DeviceVM

WIRELESS

PERSONAL CELL TOWER

MANY CELL-PHONE owners don't want to pay for landlines but are unhappy with spotty cell reception indoors. Enter the Airave, a wireless base station for the home, which transmits over normal cell-phone frequencies and offers about 5,000 square feet of coverage. The device plugs into a broadband modem and sends calls over the Internet, but recipients can use any wired or wireless phone network. Sprint has pilot programs in three U.S. cities and plans to launch the service nationally this year.

Product: Airave base station **Cost:** $0 to $50 in pilot programs; unlimited calls are $15 a month for individuals, $30 a month for families (in addition to basic calling plan) **Source:** www.sprint.com/airave **Company:** Sprint, Samsung

COURTESY OF WILDCHARGE (WILDCHARGER); CHRISTOPHER HARTING (AIRAVE)

DIAGNOSTICS

INFECTION DETECTION

MULTI-DRUG-RESISTANT staph infections have emerged as the most common skin and soft-tissue infections in the United States. If they reach the bloodstream, they can turn deadly. A new genetic test, which works on blood cultures, takes only a few hours to identify drug-resistant staph, where previous tests took days. The test kit includes reagents that detect DNA sequences characteristic of the drug-resistant and the garden-variety strains of the bacterium.

Product: GeneOhm StaphSR assay **Cost:** $39.50 per test
Source: www.bd.com/geneohm/english/products/idi_mrsa.asp
Company: BD Diagnostics

GAMING

COMPETITION FOR THE WII

LIKE THE Nintendo Wii game controller, the Motus Darwin lets video gamers control digital characters using physical gestures; unlike the Wii, it doesn't determine its position by triangulating with an infrared emitter fastened to the television. Instead, it measures gravitational forces and its own orientation with respect to magnetic north. So it doesn't get confused if its line of sight to the emitter is broken—by obstacles, or by gestures that yank it out of range.

Product: Motus Darwin
Cost: $79 to $99
Source: www.motusgames.com
Company: Motus

DISPLAYS

First Laser TV

MITSUBISHI'S new TV is the first to use laser light, which produces exceptionally vivid color. Like some existing TVs, Mitsubishi's uses an array of tiny, movable mirrors; red, blue, and green light beams strike the mirrors and are reflected onto the screen in different combinations. But because laser light is so pure—all its photons have exactly the same wavelength—the color combinations can be much more precise. The TV will be on the market by the end of the year.

Product: Laser TV **Cost:** Competitive with similar-sized flat-panel LCD TVs (where a 60- or 65-inch set might cost $7,000 to $9,000) **Source:** www.believingisseeing.tv **Company:** Mitsubishi Electric

COURTESY OF BD DIAGNOSTICS (STAPH TEST); DENISE TRUSCELLO, MITSUBISHI DIGITAL ELECTRONICS AMERICA (LASER TV); CHRISTOPHER HARTING (MOTUS)

IMAGING

A BETTER BRAIN SCANNER

A NEW magnetic resonance imaging (MRI) device that fits the subject's head like a helmet could speed up brain scans and improve their resolution. Where a conventional MRI machine might have 12 detection coils, the new system instead uses 32 small coils that are closer to the head, yielding a clearer signal. The system can produce more-accurate maps of vital brain areas, so doctors can avoid them during surgery. Eventually, it might also distinguish different types of tumors, aiding treatment decisions.

Product: Siemens coil helmet
Cost: 60,000 to 100,000 euros
Source: www.siemens.com/healthcare
Company: Siemens

PRINTERS

POCKET PHOTO LAB

POLAROID has developed an ultrasmall printer for digital photos that provides the same instant gratification its cameras are renowned for. The printer, roughly the size of a deck of cards, can connect to a cell phone wirelessly or to a camera with a USB cable. It has hundreds of tiny, precisely controllable heating elements that draw color out of specially designed two-by-three-inch photo paper. The paper has layers of nanocrystals that turn different colors depending on how long they're heated and at what temperature.

Product: Digital Instant Mobile Photo Printer **Cost:** Less than $150 for the printer; 30 to 35 cents per sheet of photo paper
Source: www.polaroid.com/onthego **Company:** Polaroid, Zink

FUEL CELLS

Water-Activated Generator

HYDROGEN fuel cells may be decades away from widespread use in cars, but later this year, consumers will be able to buy a fuel-cell generator that's light and compact enough to grab off a shelf during a blackout—or even take on a backpacking trip. The 22-centimeter-tall generator weighs about two kilograms with an unactivated fuel cartridge. Add water, plug in a device, and the system pumps sodium borohydride solution over a catalyst, freeing hydrogen to power the cell.

Product: HydroPak water-activated power system
Cost: $400; $20 per fuel cartridge **Source:** www.millenniumcell.com
Company: Horizon Fuel Cell Technologies, Millennium Cell

CHRISTOPHER HARTING (ZINK); COURTESY OF LAWRENCE WALD (MRI); COURTESY OF MILLENNIUM CELL (HYRDOPAK)

Q&A

WALTER BENDER

One Laptop per Child, now

In January 2005, MIT Media Lab cofounder Nicholas Negroponte announced the One Laptop per Child program (OLPC), which was intended to improve education in poor countries by putting $100 laptops in the hands of schoolchildren *(see "Philanthropy's New Prototype," November/December 2006)*. The laptop would not go into production, Negroponte declared, until OLPC had received five million orders from governments around the world.

Almost three years later, however, the program's two largest customers were Peru and Uruguay, which together had ordered slightly fewer than 400,000 units. So in November 2007, OLPC began manufacturing laptops anyway, at a cost of roughly $188 apiece. At about the same time, OLPC began its holiday-season Give One Get One drive: any donor who contributed $399 to the project would receive a complimentary computer, and a second would be sent to a poor community. The drive raised $35 million to "bootstrap" laptop programs in countries including Mongolia, Haiti, Rwanda, Ethiopia, Cambodia, and Afghanistan, each of which will initially receive around 10,000 laptops.

In January, *TR* senior editor Larry Hardesty spoke with OLPC's president for software and content, Walter Bender.

***TR*: Initially, you thought you'd need millions of advance orders to get the cost of the laptop down. Why wasn't that the case?**

Bender: The correlation between volume and price wasn't as extreme as we thought. Well, in the long run, it is. In the long run, you're not going to do a large-scale integration without having sufficient volume to cover the nonrecurring costs. But because we raised money to cover all the nonrecurring costs for the [current] machine, we didn't have to amortize any costs in the cost of the laptop.

In the absence of large-volume orders, though, couldn't you just run out of money before you reach critical mass?

We don't need a lot of money to keep One Laptop per Child going. It's really more a matter of just keeping the factory running. And basically, we scale the factory based on the volume.

But the Give One Get One program built volume by manufacturing demand.

We actually manufactured more volume than the factory can manage right now. Which is why people are saying, "Where's my laptop?" Because we don't have the manufacturing capacity to deliver everybody their laptops yet. So in fact, we've got more volume in orders than we can fulfill right now.

You've said that the point of the program is to get laptops into kids' hands, and you don't really care who ends up manufacturing them. But was that part of OLPC's mission from the outset?

Absolutely. One could argue that the need is one to two billion children. And as arrogant as a bunch of former MIT people can be, we're not so arrogant as to suggest that we can service that need ourselves. We've built what I think is an amazing machine, but it's inevitable that there will be other amazing machines that will emerge. And since our mission is one laptop per child—it's not one green-and-white laptop per child—that's great.

So how does your laptop stack up against the others that are beginning to compete with it? Intel's Classmate or the Asus Eee …

I don't think much of the Classmate as a machine. I think it consumes too much power; I think it's got a crappy display that's not suitable for reading. A lot of the kids, this is their only book. And to read on a display that's designed for a portable DVD player is not exactly useful.

This will be kids' only book?

You go to even a relatively wealthy country like Nigeria. You go to one of the major cities there, Abuja, which is the capital city, their model city. And you go to a school in Abuja, and they've got 80 kids in a classroom and two or three books for those 80 kids. And if you go outside of Abuja to the countryside, they're lucky if they have that.

How about the other competitors?

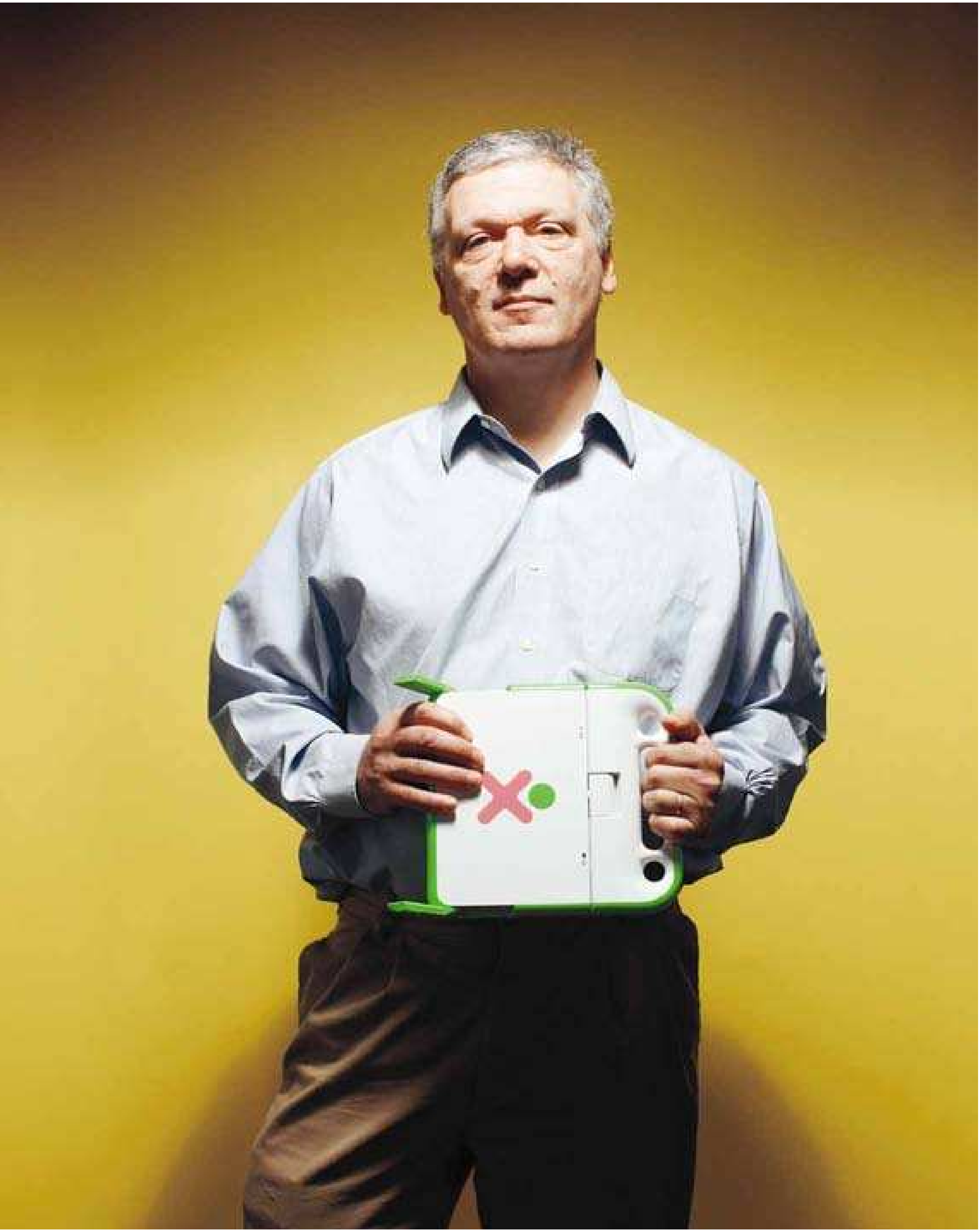
One thing to consider is, what's the cost of ownership over a five-year lifetime? There are several issues: How do you provide power to the laptop? How much power does the laptop require? What's the lifetime of the battery system? We designed our battery system to have a 2,000-cycle lifetime, which means that if you cycle through [drain and recharge the battery] once a day, that's going to last five years. Whereas the typical laptop battery lasts 500 cycle times, so that's less than a year and a half. And the replacement cost of the battery is, in our case, less than 10 dollars. I don't know in these other systems, but I would guess that it would be three or four or five or so times that.

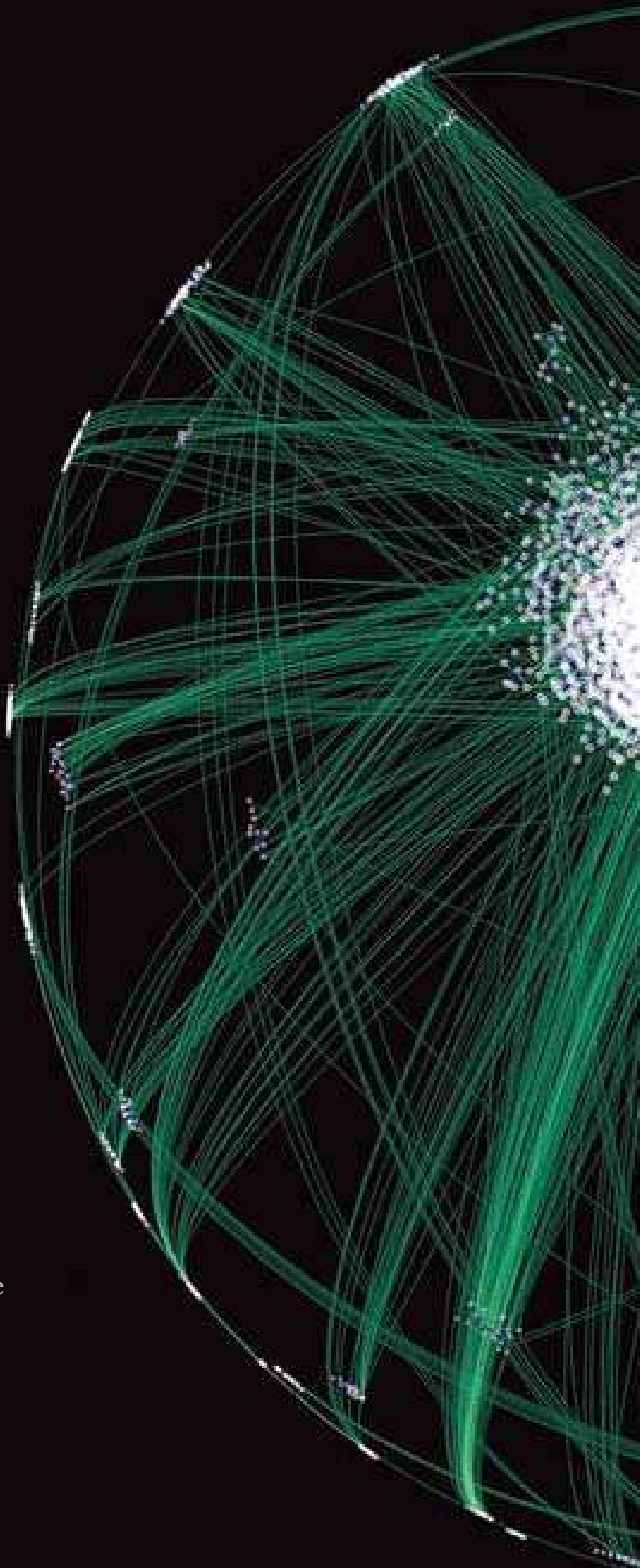
But then there's the other question: So I charge my machine at school, and I take it home. So first of all, how long is the machine going to run on battery charge? How long can I read my book for? Am I a slow reader? So we've designed the e-book to run for—actually, we have a target of close to 24 hours, but we can achieve probably half of that using our current power management scheme.

OLPC's former chief technology officer, Mary Lou Jepsen, recently started her own company and immediately announced plans to build a $75 laptop. If she succeeds, what will your reaction be?

Hallelujah. Hallelujah. TR

Photograph by CHRISTOPHER CHURCHILL



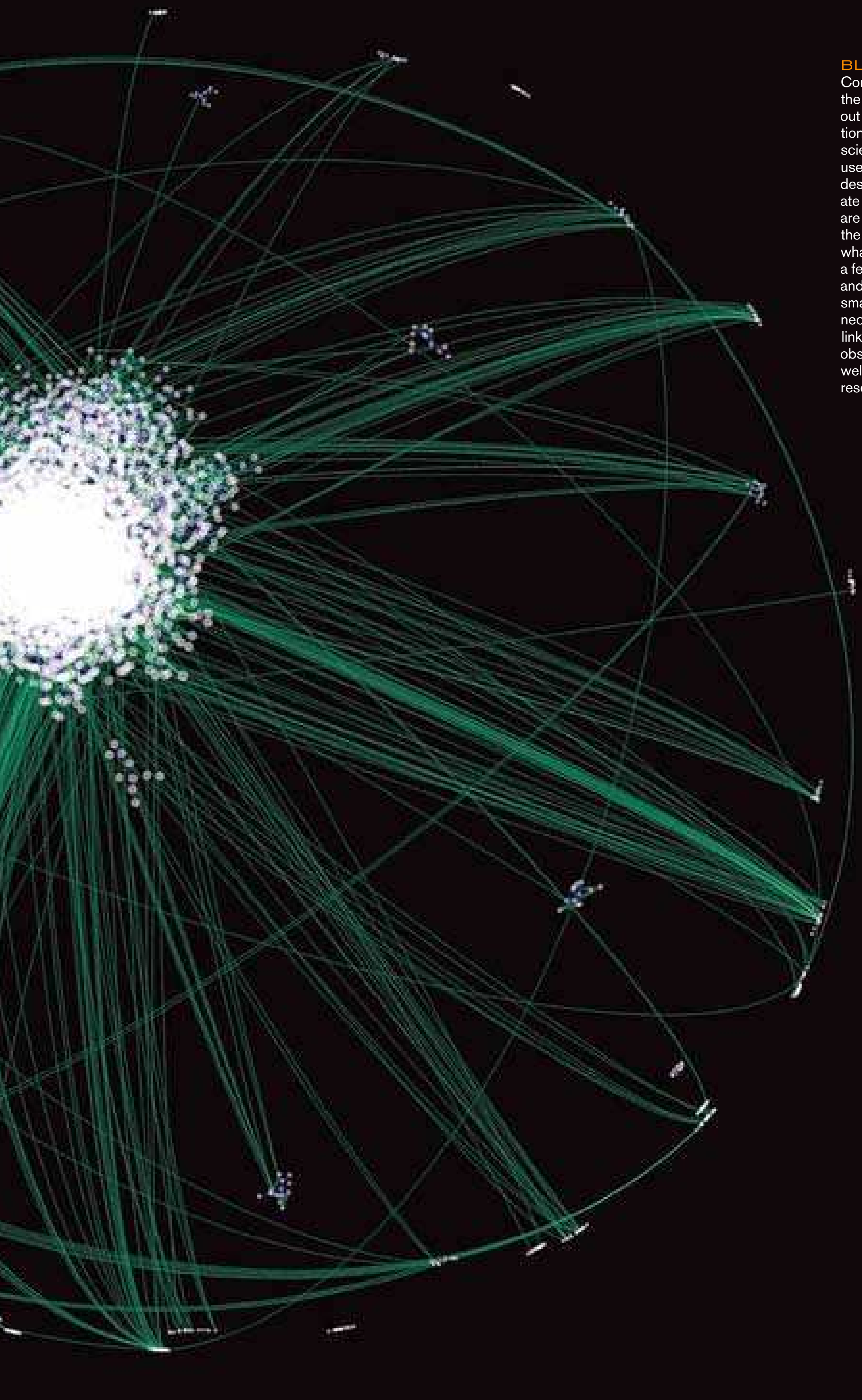


VISUALIZATION

BETWEEN FRIENDS

The idea of a social graph—a representation of a person's network of friends, family, and acquaintances—gained currency last year as the popularity of online social networks grew: Facebook, for example, claims to have more than 64 million active users, with 250,000 more signing up each day. It and other sites have tried to commercialize these social connections by allowing outside developers to build applications that access users' networks. Facebook also advertises to a user's contacts in accordance with the user's online buying habits. The push to understand the nature and potential value of links between people online has led to imaginative ways to represent such networks. Here, we look at some of them.

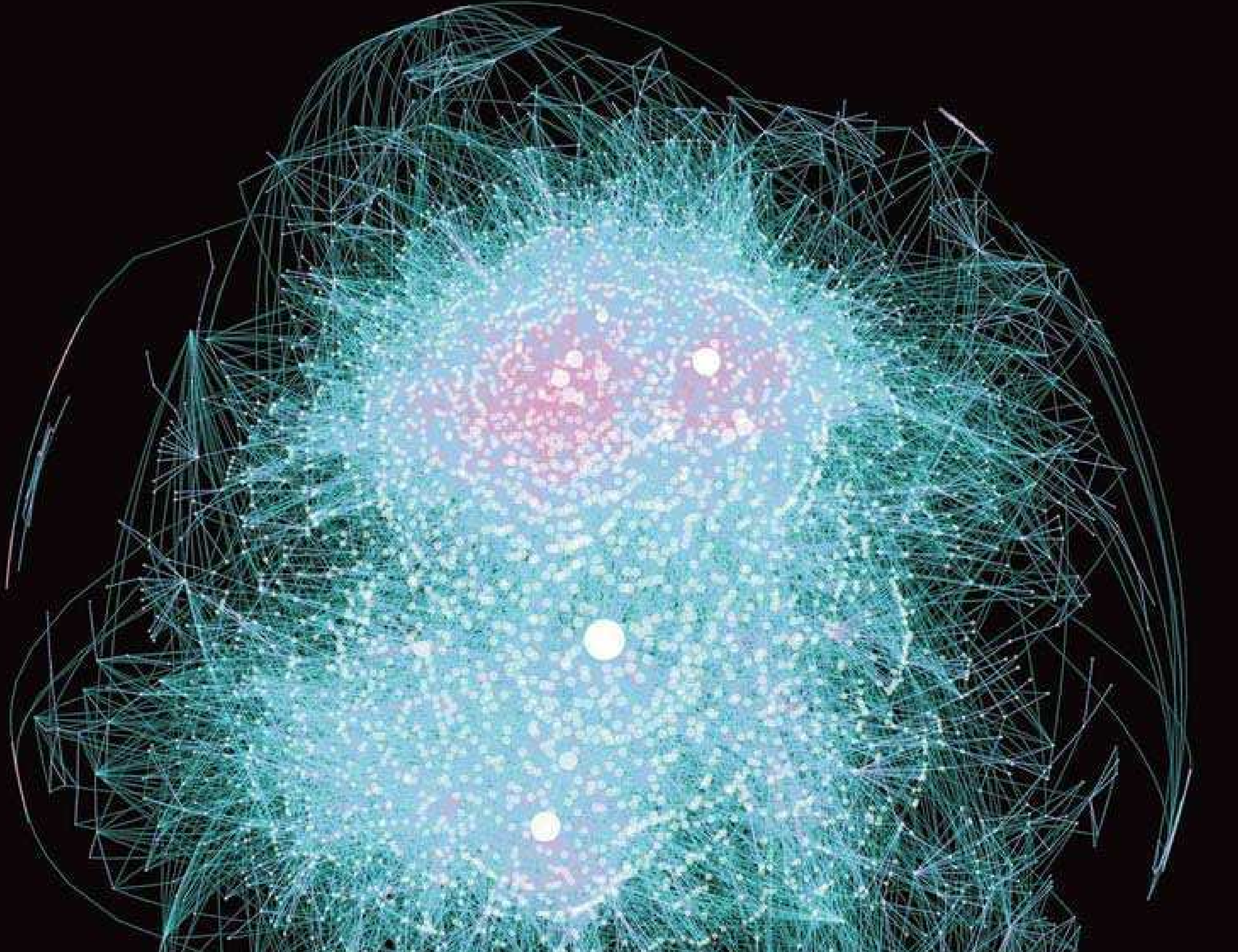
By ERICA NAONE

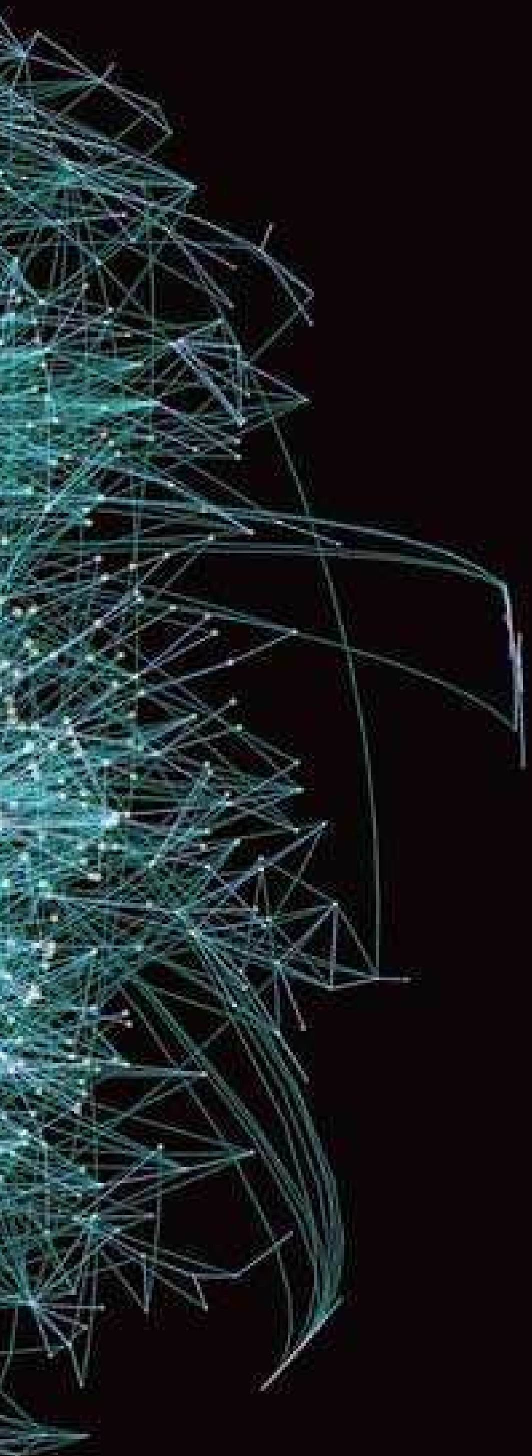


BLOGOSPHERE

Communities that form around the exchange of information stand out in Matthew Hurst's visualizations of the blogosphere. Hurst, a scientist at Microsoft's Live Labs, used a search tool he helped design, called Blogpulse, to generate the data on which his images are based. The dense cluster at the center of this image represents what Hurst calls the core, a set of a few thousand blogs with links to and from many other sites. Other, smaller blogging communities connect to the core through one-way links (usually produced when an obscure blog at the edge links to a well-known blog at the core), represented here by hairlike strands.

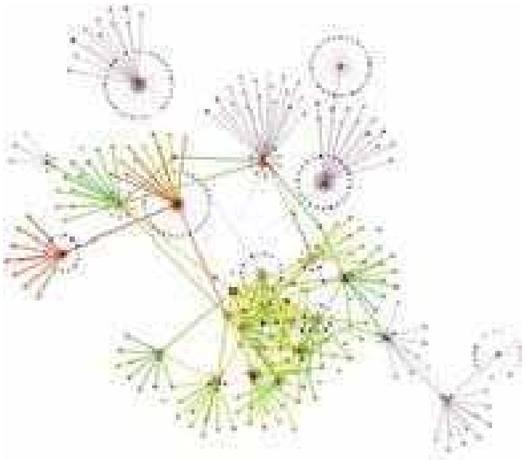
MATTHEW HURST





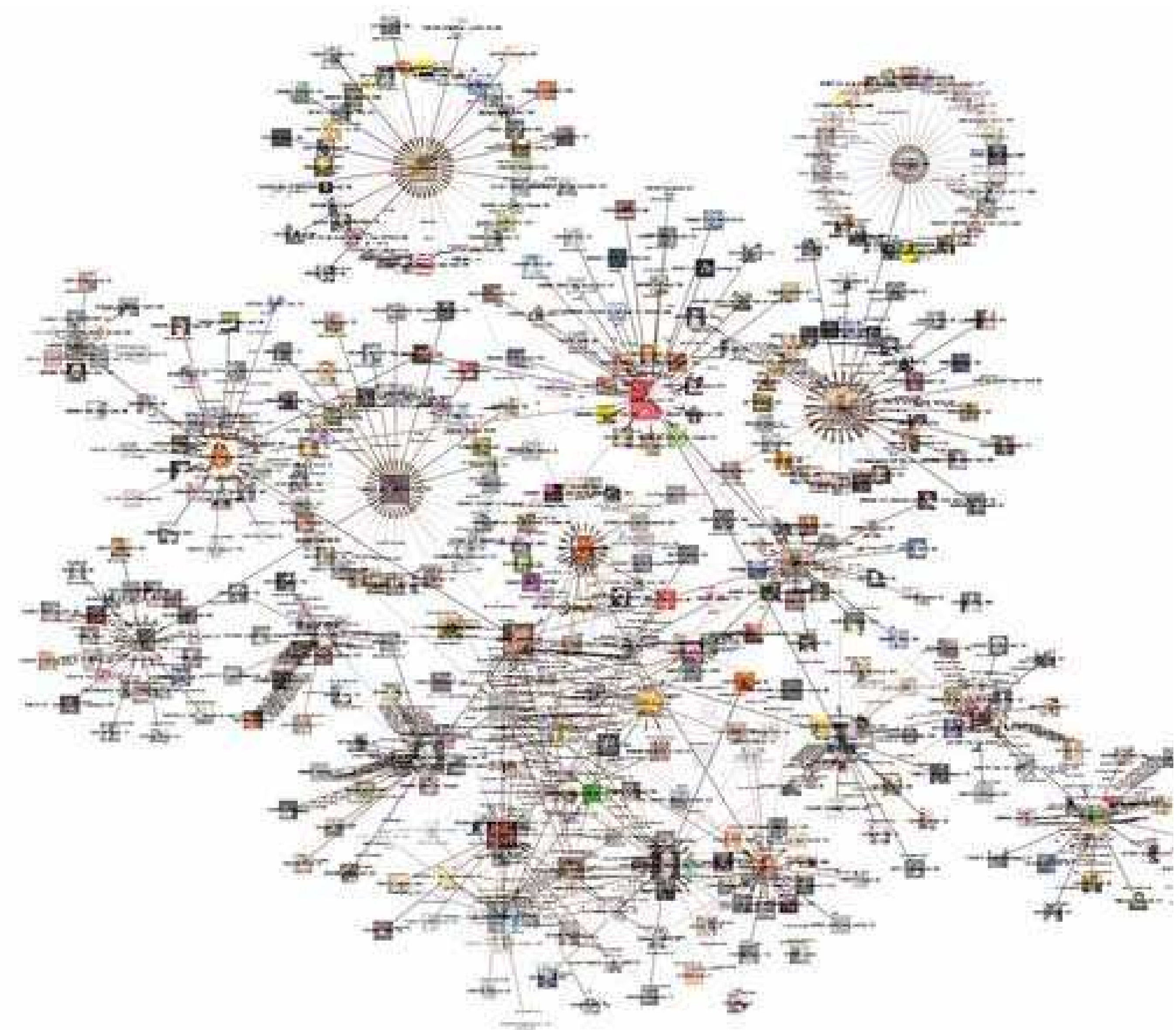
BLOGOSPHERE
The core of the blogosphere, made up of several thousand popular blogs that are heavily connected to one another, divides into two regions when seen up close. The region on the left, at the center of which are two areas showing a lot of pink, contains political blogs; the region on the right, divided from the first by the triangular indentation at the bottom, contains blogs focused on gadgets and technology. The two regions are held together by popular blogs with ties to both subject areas. The size of the circle representing a given blog is proportional to the number of other blogs linked to it. Hurst notes an apparent difference in culture between the two regions: pink lines, which represent reciprocal links, are much denser among the political blogs than they are among blogs focused on technology.

MATTHEW HURST



COMMENT FLOW

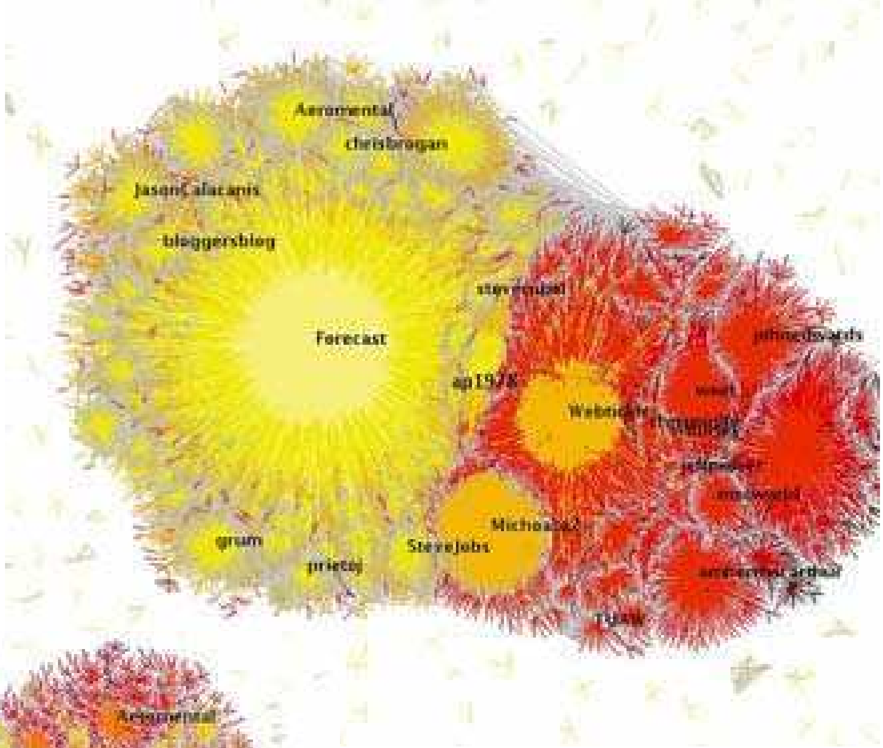
Maps of online social networks often reveal little more than the fact that two users have linked to each other's profiles. That type of map becomes meaningless when, as is typical on MySpace, many users have more than 100 such links and sometimes as many as a million, says Dietmar Offenhuber, a research assistant at the MIT Media Lab. The Comment Flow visualization he created with associate professor Judith Donath traces actual communication between users. Offenhuber and Donath created these images by tracking where and how often users left comments for other users; connections are based on these patterns, rather than on whether people have named each other as "friends." As the time since the last communication grows, the visual connection begins to fade. The image can include profile pictures and the text of the comments passing between users. Offenhuber says the tool can help users assess the communication habits of prospective friends at a glance. For example, a user who emits a thick flow of similar messages to a wide group of contacts might be a spammer posing as a friendly contact in order to post advertising on people's profile pages.

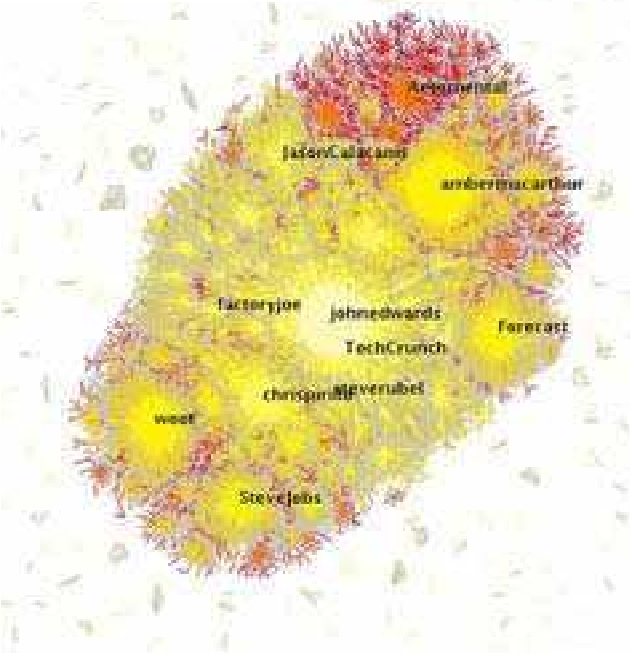


DIETMAR OFFENHUBER, JUDITH DONATH, MIT SOCIABLE MEDIA GROUP

TWITTER SOCIAL NETWORK

People have different intentions when they share information through social networks, says Akshay Java, a member of the eBiquity Research Group at the University of Maryland, Baltimore County. He cites three purposes that bring users to the microblogging site Twitter, where they share brief updates via text message, instant messenger, and the Twitter website: finding information, sharing information, and having conversations. These images show the different networks produced by the different types of communication. When all connections as of April 2007 are mapped (top), news sources appear as huge nodes. When maps show only mutual relationships (bottom), in which all users both share and receive information, nodes are smaller and the network appears more tightly knit. (The different colors reflect a loose attempt to group close contacts together.)

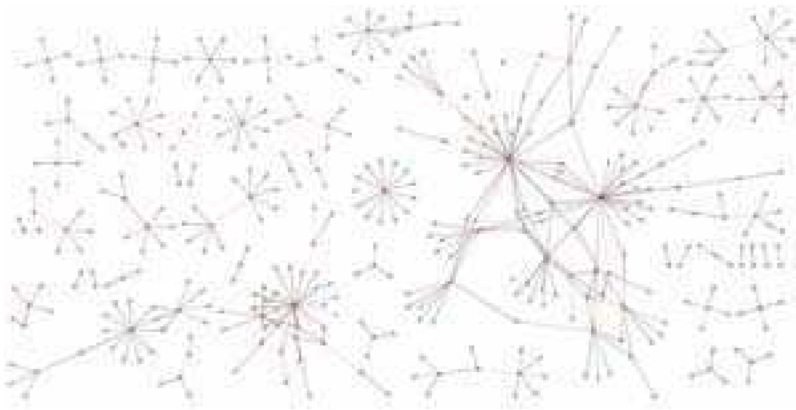




ATLAS

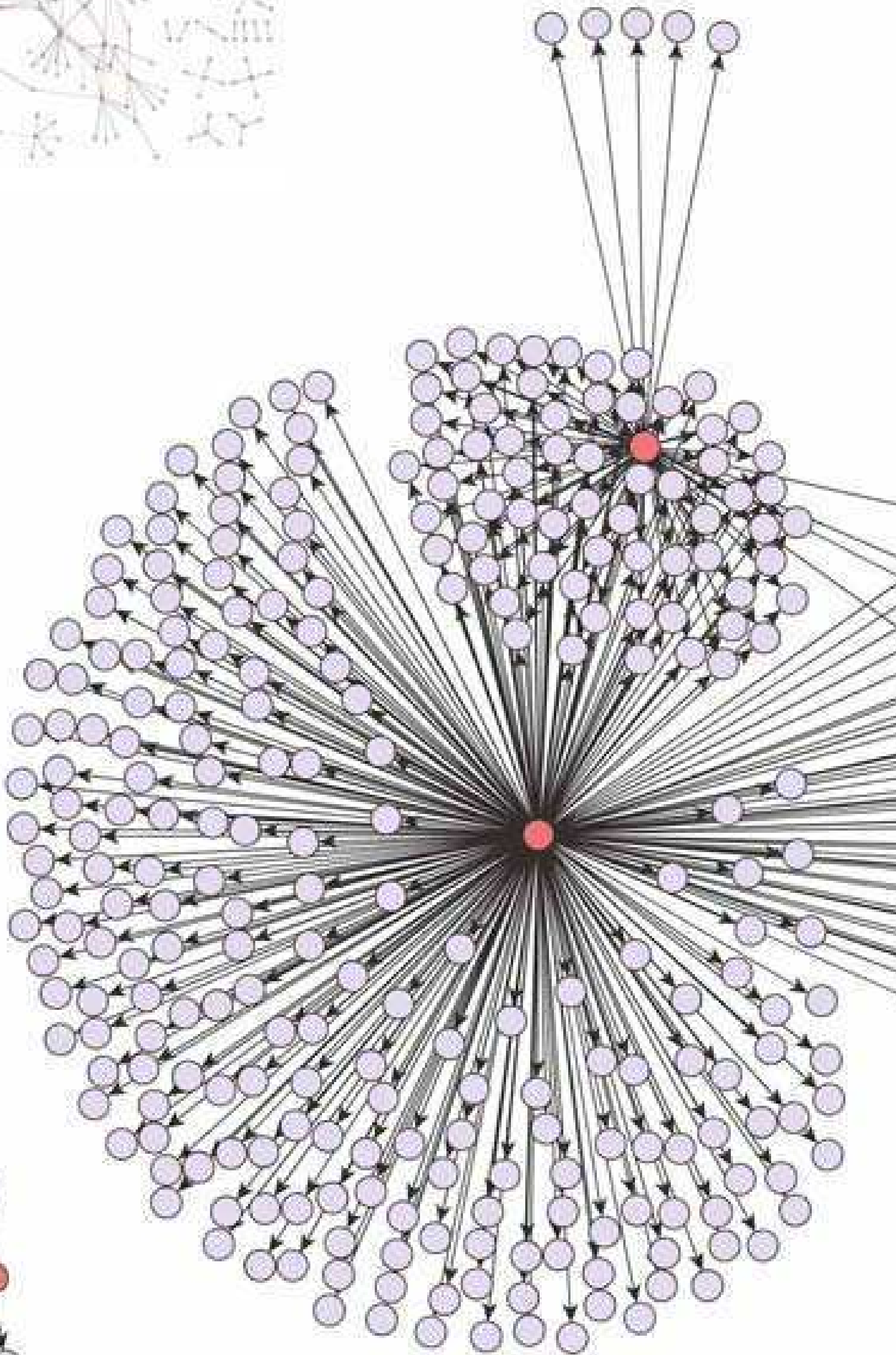
IBM's Atlas maps social networks in the workplace; the program's MyNet component can identify users' connections on the basis of their relative positions within the company and their communications by e-mail and instant messenger. The resulting map not only shows contacts (along with their locations and organizations) but also measures how close they are. One view shows particularly close contacts near the center of the diagram and distant ones toward the perimeter. Chris Lamb, senior product manager for IBM's Lotus Connections software, says workers can use the tool to maintain their professional networks. For example, a person might notice an important contact drifting toward the perimeter of the circle and take steps to catch up before the connection fades.

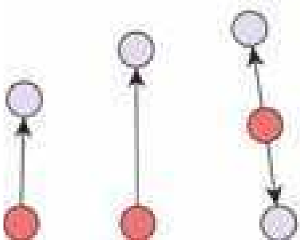
IBM (ATLAS); AKSHAY JAVA, UMBC EBIQUITY RESEARCH GROUP (TWITTER)



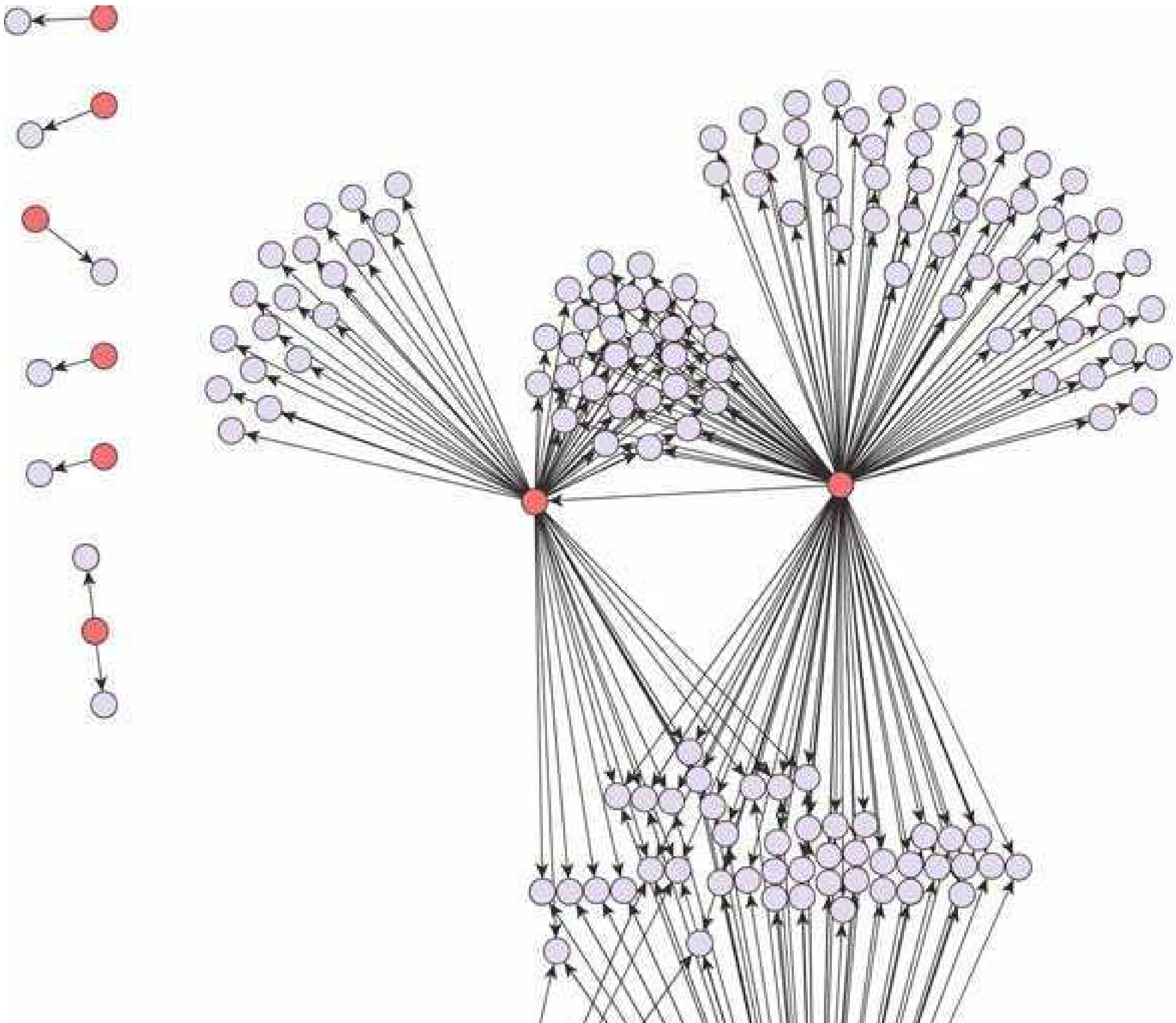
VIRAL MARKETING

Several years ago, a large retailer tried to encourage word-of-mouth marketing for products sold on its site by offering incentives to site visitors who made product recommendations. Many companies are trying to use people's social connections for such "viral marketing" programs, hoping that information about products (and the urge to buy them) can spread through a network of people the way a virus might. But after studying more than 15 million recommendations generated by the retailer's incentive program, a team made up of Jure Leskovec, Lada Adamic, and Bernardo Huberman, director of the information dynamics lab at Hewlett-Packard, was skeptical. Huberman and his colleagues looked at the networks that grew up around each product—who bought and recommended it, and who responded to the recommendation—and saw that they took on different characteristics depending on the type of product. A network around a medical book (above), where red dots and lines indicate people who purchased the book while blue dots and lines represent people who received a recommendation, shows a scattered network where recommendations, on average, don't travel very far. The network surrounding a Japanese graphic novel (right), on the other hand, shows a thick flow of information among densely connected people. The researchers found that viral marketing was most effective for expensive products recommended within a small, tightly connected group. They also found that overusing consumers' social connections for marketing can make them less influential.





JURE LESKOVEC, LADA ADAMIC, BERNARDO HUBERMAN, FROM "THE DYNAMICS OF VIRAL MARKETING," ACM TRANSACTIONS ON THE WEB, VOL. 1, ISSUE 1, MAY 2007



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John Doerr
Partner, Kleiner Perkins Caufield & Byers

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Afternoon Keynote

James E. Rogers
Chairman, President and Chief Executive Officer, Duke Energy

Saturday Speakers include:

John Holdren, Teresa and John Heinz Professor of Environmental Policy, Harvard University
Jackalyne Pfannenstiel, Chair, California Energy Commission
Jefferson W. Tester, H. P. Meissner Professor of Chemical Engineering, MIT
John B. Heywood, Sun Jae Professor of Mechanical Engineering, MIT
Howard Herzog, Principal Research Engineer, MIT Energy Initiative

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EMERGING TECHNOLOGIES 2008

Each year, *Technology Review* publishes its list of 10 emerging technologies that its editors believe will be particularly important over the next few years. This is work ready to emerge from the lab, in a broad range of areas: energy, computer hardware and software, biological imaging, and more. Two of the technologies—cellulolytic enzymes and atomic magnetometers—are efforts by leading scientists to solve critical problems, while five—surprise modeling, connectomics, probabilistic CMOS, reality mining, and offline Web applications—represent whole new ways of *looking* at problems. And three—graphene transistors, nanoradio, and wireless power—are amazing feats of engineering that have created something entirely new.

SUE TALLON

ENERGY

Cellulolytic Enzymes

FRANCES ARNOLD IS TAKING ON ONE OF THE BIGGEST CHALLENGES IN THE BIOFUELS INDUSTRY: DESIGNING BETTER ENZYMES FOR BREAKING DOWN CELLULOSE. *BY ALEXANDRA GOHO*

In December, President Bush signed the Energy Independence and Security Act of 2007, which calls for U.S. production of renewable fuels to reach 36 billion gallons a year—nearly five times current levels—by 2022. Of that total, cellulosic biofuels derived from sources such as agricultural waste, wood chips, and prairie grasses are supposed to account for 16 billion gallons. If the mandates are met, gasoline consumption should decline significantly, reducing both greenhouse-gas emissions and imports of foreign oil.

The ambitious plan faces a significant hurdle, however: no one has yet demonstrated a cost-competitive industrial process for making cellulosic biofuels. Today, nearly all the ethanol produced in the United States is made from the starch in corn kernels, which is easily broken down into the sugars that are fermented to make fuel. Making ethanol from cheaper sources will require an efficient way to free sugar molecules packed together to form crystalline chains of cellulose, the key structural component of plants. That's "the most expensive limiting step right now for the large-scale commercialization of [cellulosic] biofuels," says protein engineer Frances Arnold, a professor of chemical engineering and biochemistry at Caltech.

The key to more efficiently and cheaply breaking down cellulose, Arnold and many others believe, is better enzymes. And Arnold, who has spent the last two decades designing enzymes for use in everything from drugs to stain removers, is confident that she's well on her way to finding them.

Cellulosic biofuels have many advantages over both gasoline and corn ethanol. Burning cellulosic ethanol rather than gasoline, for instance, could cut cars' greenhouse-gas emissions by 87 percent; corn ethanol achieves reductions of just 18 to 28 percent. And cellulose is the most abundant organic material on earth.

But whereas converting cornstarch into sugar requires a single enzyme, breaking down cellulose involves a complex array of enzymes, called cellulases, that work together. In the past, cellulases found in fungi have been recruited to do the job, but they have proved too slow and unstable. Efforts to improve their performance by combining them in new ways or tweaking their constituent amino acids have been only moderately successful. Researchers have reduced the cost of industrial cellulolytic enzymes to 20 to 50 cents per gallon of ethanol produced. But the cost will have to fall to three or four cents per gallon for cellulosic ethanol to compete with corn ethanol.

WHO
Frances Arnold, Caltech

DEFINITION
Cellulolytic enzymes break down the cellulose found in biomass so it can be used as a feedstock for biofuels.

IMPACT
Increased use of cellulosic biofuels could cut greenhouse-gas emissions and reduce reliance on oil.

CONTEXT
Processes for making cellulosic biofuels are still too expensive to be practical. A number of companies are racing to find a solution.

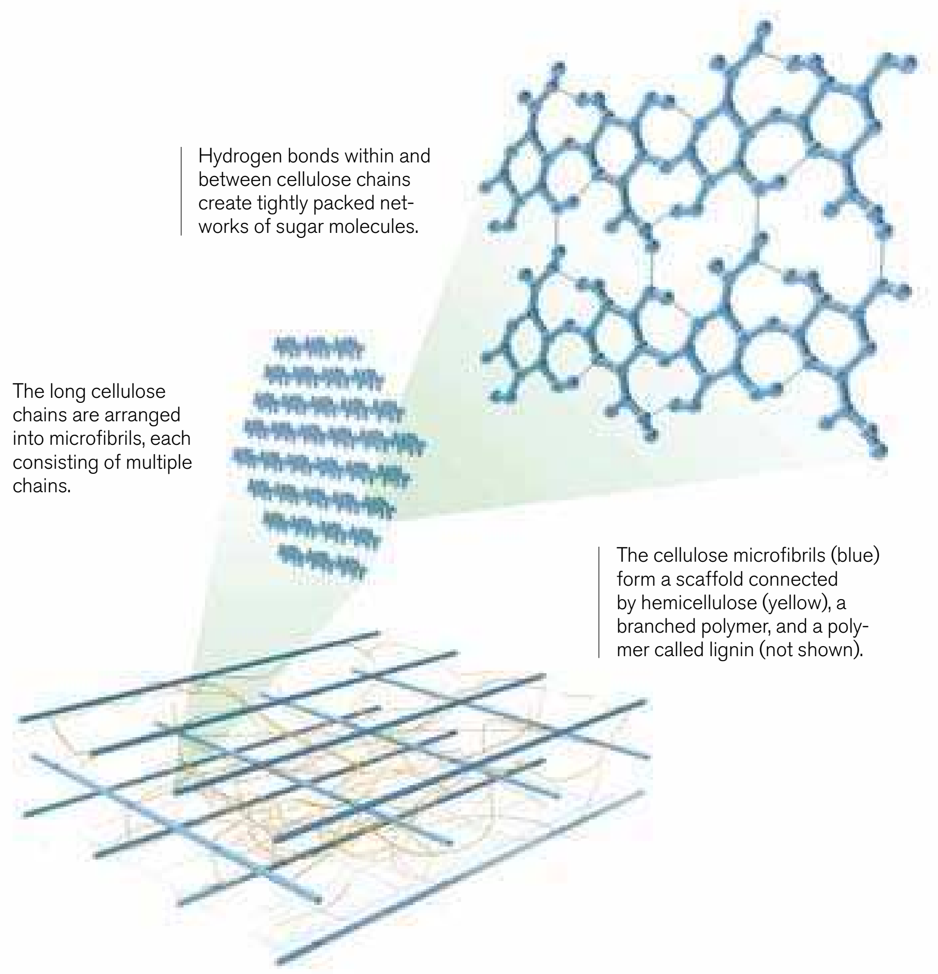
Ultimately, Arnold wants to do more than just make cheaper, more efficient enzymes for breaking down cellulose. She wants to design cellulases that can be produced by the same microörganisms that ferment sugars into biofuel. Long a goal of researchers, "superbugs" that can both metabolize cellulose and create fuel could greatly lower the cost of producing cellulosic biofuels. "If you consolidate these two steps, then you get synergies that lower the cost of the overall process," Arnold says.

Consolidating those steps will require cellulases that work in the robust organisms used in industrial fermentation processes—such as yeast and bacteria. The cellulases will need to be stable and highly active, and they'll have to tolerate high sugar levels and function in the presence of contaminants. Moreover, researchers will have to be able to produce the organisms in sufficient quantities. This might seem like a tall order, but over the years, Arnold has developed a number of new tools for making novel proteins. She pioneered a technique, called directed evolution, that involves creating many variations of genes that code for specific proteins. The mutated genes are inserted into microörganisms that churn out the new proteins, which are then screened for particular characteristics.

Her latest strategy is a computational approach that can rapidly identify thousands of new protein sequences for screening. This approach generates many more sequence variants than other methods do, greatly increasing the chances of creating functional molecules with useful new properties.

GREGG SEGAL

Frances Arnold



CELLULOSIC COMPLEXITY

The precise arrangement of cellulose chains within plant cell walls makes them highly resistant to enzymatic attack. The network of hydrogen bonds both within and between chains, plus the presence of hemicellulose and lignin polymers, restricts the ability of cellulolytic enzymes to free the sugar molecules that compose the chains, a necessary step for biofuel production.

Arnold is using the technique to build libraries containing thousands of new cellulase genes. She and her colleagues will then screen the cellulases to see how they act as part of a mixture of enzymes. "If you test them simply by themselves, you really don't know how they work as a group," she says.

To fulfill her ultimate goal of a superbug able to feed on cellulose and produce biofuels, Arnold is working with James Liao, a professor of chemical engineering at the University of California, Los Angeles. Liao recently engineered *E. coli* that can efficiently convert sugar into butanol, a higher-energy biofuel than ethanol. Arnold hopes to be able to incorporate her new enzymes into Liao's butanol-producing microbes. Gevo, a startup cofounded by Arnold and based in Denver, CO, has licensed Liao's technology for use in the large-scale production of advanced biofuels, including butanol.

Overcoming cellulose's natural resistance to being broken down is "one of the most challenging protein-engineering problems around," says Arnold. Solving it will help determine whether low-emission biofuels will ever be a viable substitute for fossil fuels.

INFOTECH

REALITY MINING

Sandy Pentland is using data gathered by cell phones to learn more about human behavior and social interactions. *By Kate Greene*

Every time you use your cell phone, you leave behind a few bits of information. The phone pings the nearest cell-phone towers, revealing its location. Your service provider records the duration of your call and the number dialed.

Some people are nervous about trailing digital bread crumbs behind them. Sandy Pentland, however, revels in it. In fact, the MIT professor of media arts and sciences would like to see phones collect even more information about their users, recording everything from their physical activity to their conversational cadences. With the aid of some algorithms, he posits, that information could help us identify things to do or new people to meet. It could also make devices easier to use—for instance, by automatically determining security settings. More significant, cell-phone data could shed light on workplace dynamics and on the well-being of communities. It could even help project the course of disease outbreaks and provide clues about individuals' health. Pentland, who has been sifting data gleaned from mobile devices for a decade, calls the practice "reality mining."

Reality mining, he says, "is all about paying attention to patterns in life and using that information

BRYAN CHRISTIE DESIGN

to help [with] things like setting privacy patterns, sharing things with people, notifying people—basically, to help you live your life."

Researchers have been mining data from the physical world for years, says Alex Kass, a researcher who leads reality-mining projects at Accenture, a consulting and technology services firm. Sensors in manufacturing plants tell operators when equipment is faulty, and cameras on highways monitor traffic flow. But now, he says, "reality mining is getting personal."

Within the next few years, Pentland predicts, reality mining will become more common, thanks in part to the proliferation and increasing sophistication of cell phones. Many handheld devices now have the processing power of low-end desktop computers, and they can also collect more varied data, thanks to devices such as GPS chips that track location. And researchers such as Pentland are getting better at making sense of all that information.

To create an accurate model of a person's social network, for example, Pentland's team combines a phone's call logs with information about its proximity to other people's devices, which is continuously collected by Bluetooth sensors. With the help of factor analysis, a statistical technique commonly used in the social sciences to explain correlations among multiple variables, the team identifies patterns in the data and translates them into maps of social relationships. Such maps could be used, for instance, to accurately categorize the people in your address book as friends, family members, acquaintances, or coworkers. In turn, this information could be used to automatically establish privacy settings—for instance, allowing only your family to view your schedule. With location data added in, the phone could predict when you would be near someone in your network. In a paper published last May, Pentland and his group showed that cell-phone data enabled them to accurately model the social networks of about 100 MIT students and professors. They could also precisely predict where subjects would meet with members of their networks on any given day of the week.

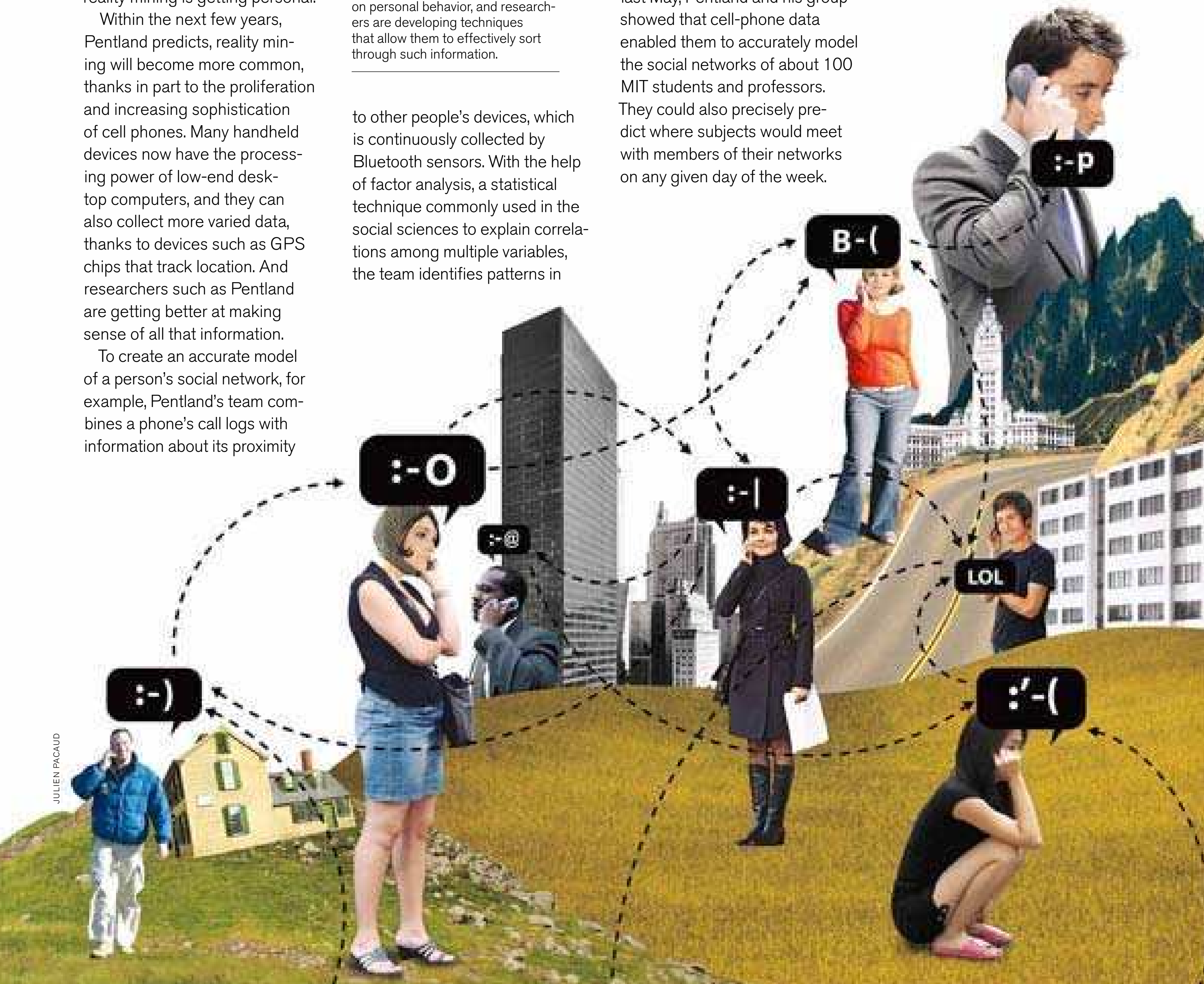
This relationship information could have much broader implications. Earlier this year, Nathan Eagle, a former MIT grad student who had led the reality-mining research in Pentland's lab, moved to the Santa Fe Institute in New Mexico. There, he plans to use cell-phone data to improve existing computational models of how diseases like SARS spread. Most epidemiology models don't back up their predictions with detailed data on where and with whom people spend their

WHO
Sandy Pentland, MIT

DEFINITION
Personal reality mining infers human relationships and behavior by applying data-mining algorithms to information collected by cell-phone sensors that can measure location, physical activity, and more.

IMPACT
Models generated by analyzing data from both individuals and groups could enable automated security settings, smart personal assistants, and monitoring of personal and community health.

CONTEXT
Cell phones are now sophisticated enough to collect and analyze data on personal behavior, and researchers are developing techniques that allow them to effectively sort through such information.



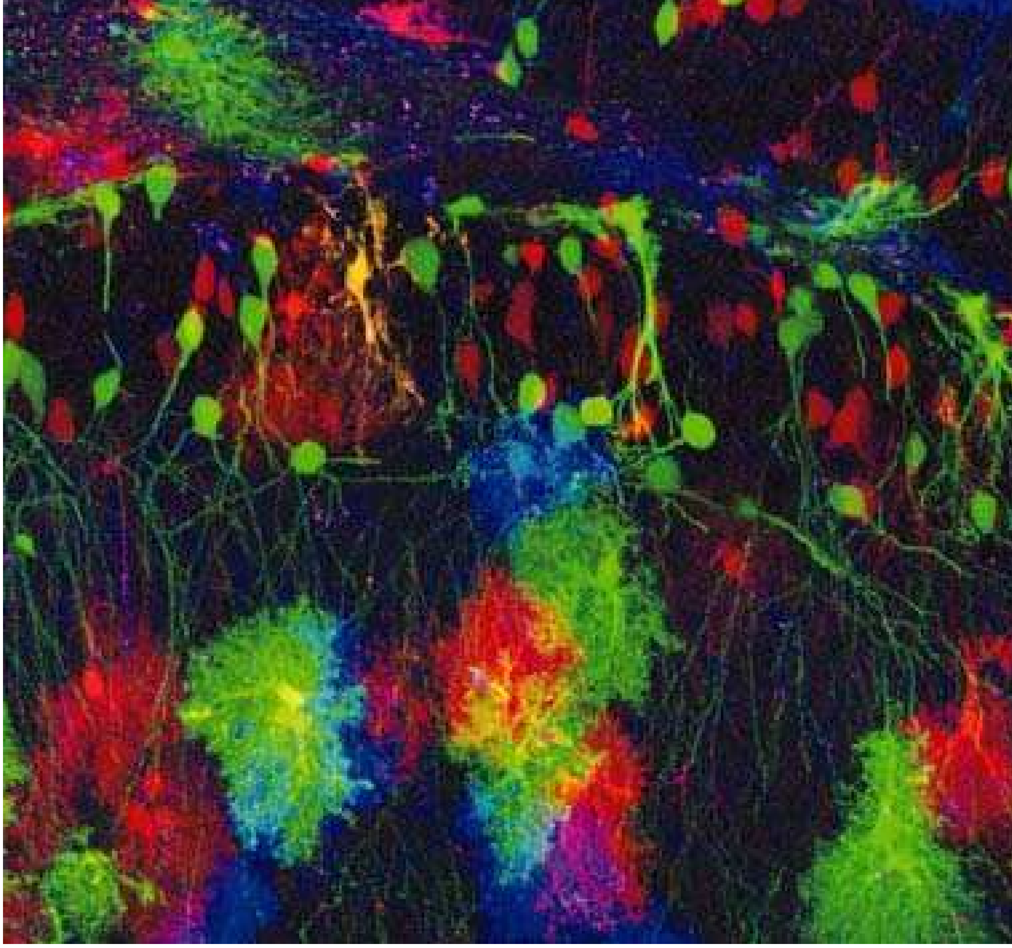
JULIEN PACAUD

time, Eagle says. The addition of relationship and proximity data would make these models more accurate. "What's interesting is that you can see that a disease spreads based on who is infected first," Eagle says.

Taking advantage of other sensors in cell phones, such as the microphone or the accelerometers built into newer devices like Apple's iPhone, could even extend the benefits of reality mining into personal health care, Pentland says. For example, clues to diagnosing depression could be found in the way a person talks: depressed people may speak more slowly, a change that speech analysis software on a phone might recognize more readily than friends or family do. Monitoring a phone's motion sensors might reveal slight changes in gait, which could be an early indicator of ailments such as Parkinson's disease.

While the promise of reality mining is great, the idea of collecting so much personal information naturally raises many questions about privacy, Pentland admits. He says it's crucial that behavior-logging technology not be forced on anyone. But legal statutes are lagging behind our data collection abilities, he says, which makes it all the more important to begin discussing how the technology will be used.

For now, though, Pentland is excited about the potential of reality mining to simplify people's lives. "All of the devices that we have are completely ignorant of the things that matter most," he says. "They may know all sorts of stuff about Web pages and phone numbers. But at the end of the day, we live to interact with other people. Now, with reality mining, you can see how that happens ... it's an interesting God's-eye view."



NEUROSCIENCE

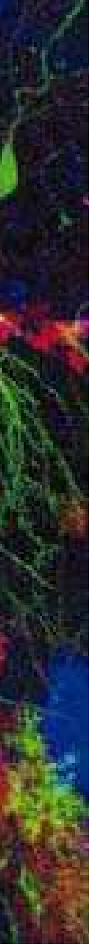
Connectomics

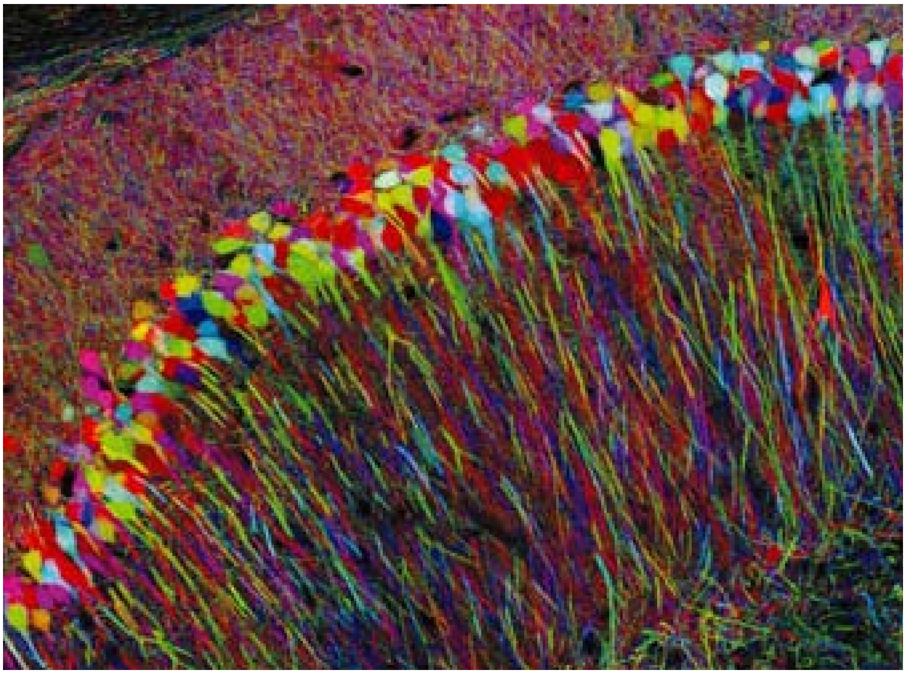
JEFF LICHTMAN HOPES TO ELUCIDATE BRAIN DEVELOPMENT AND DISEASE WITH NEW TECHNOLOGIES THAT ILLUMINATE THE TANGLED WEB OF NEURAL CIRCUITS. *BY EMILY SINGER*

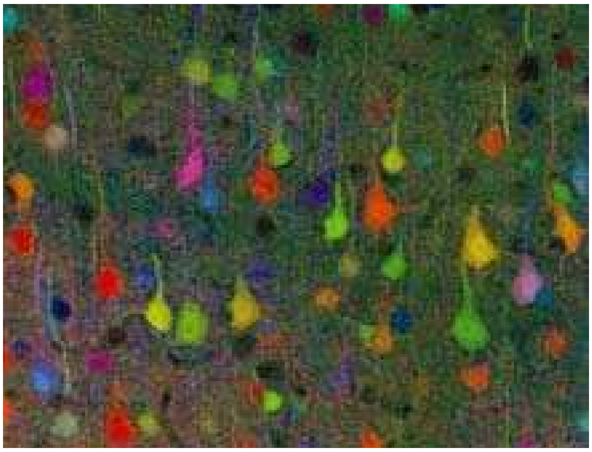
Displayed on Jeff Lichtman's computer screen in his office at Harvard University is what appears to be an elegant drawing of a tree. Thin multicolored lines snake upward in parallel, then branch out in twos and threes, their tips capped by tiny leaves. Lichtman is a neuroscientist, and the image is the first comprehensive wiring diagram of part of the mammalian nervous system. The lines denote axons, the long, hairlike extensions of nerve cells that transmit signals from one neuron to the next; the leaves are synapses, the connections that the axons make with other neurons or muscle cells.

The diagram is the fruit of an emerging field called "connectomics," which attempts to physically map the tangle of neural circuits that collect, process, and archive information in the nervous system. Such maps could ultimately shed light on the early development of the human brain and on diseases that may be linked to faulty wiring, such as autism and schizophrenia. "The brain is essentially a computer that wires itself up during development and can rewire itself," says Sebastian Seung, a computational neuroscientist at MIT, who is working with Lichtman. "If we have a wiring diagram of the brain, that could help us understand how it works."

Although researchers have been studying neural connectivity for decades, existing tools don't offer the resolution needed to reveal how the brain works. In particu-







BRAINBOWS Genetically engineering mice so that their brain cells express different combinations of fluorescent colors reveals the brain's complicated anatomy. Opposite page: Round green neurons are interspersed with diffuse support cells called astrocytes. Top left: Neurons in the hippocampus, a brain area involved in memory, are labeled in different colors, with their neural projections pointing downward. Bottom left: Neurons in the cortex.

JEAN LIVET (LEFT AND BOTTOM RIGHT); TAMILY A. WEISSMAN (TOP RIGHT)

WHO
Jeff Lichtman, Harvard University

DEFINITION
Connectomics aims to map all synaptic connections between neurons in the mammalian brain.

IMPACT
The wiring diagrams being generated should lead to better understanding of diseases such as autism and schizophrenia, as well as new insight into learning and other cognitive functions.

CONTEXT
Advances in imaging, molecular biology, and computation are converging to make it possible to generate these complex maps.

lar, scientists haven't been able to generate a detailed picture of the hundreds of millions of neurons in the brain, or of the connections between them.

Lichtman's technology—developed in collaboration with Jean Livet, a former postdoc in his lab, and Joshua Sanes, director of the Center for Brain Science at Harvard—paints nerve cells in nearly 100 colors, allowing scientists to see at a glance where each axon leads. Understanding this wiring should shed light on how information is processed and transferred between different brain areas.

To create their broad palette, Lichtman and his colleagues genetically engineered mice to carry multiple copies of genes for three proteins that fluoresce in different colors—yellow, red, or cyan. The mice also carry DNA encoding an enzyme that randomly rearranges these genes so that individual nerve cells produce an arbitrary combination of the fluorescent proteins, creating a rainbow of hues. Then the researchers use fluorescence microscopy to visualize the cells.

"This will be an incredibly powerful tool," says Elly Nedivi, a neuroscientist at MIT who is not involved in the research. "It will open up huge opportunities in terms of looking at neural connectivity."

Lichtman and others hope that the ability to study multiple neural circuits simultaneously and in depth will provide unprecedented insight into how the wiring of the nervous system can go awry. "There's a whole class of disorders of the nervous system that people suspect are due to defects in the connections between nerve cells, but we don't have real tools to trace the connections," says Lichtman. "It would be very useful to look at wiring in animal models of autism-spectrum disorders or psychiatric illness."

In experiments so far, Lichtman's group has used the technology to trace all the connections in a small slice of the cerebellum, the part of the brain that controls balance and movement. Other scientists have already expressed interest in using the technology to study neural connections in the retina, the cortex, and the olfactory bulb, as well as in non-neural cell types.

Generating maps of even a small chunk of the brain will be a huge challenge: the human brain consists of an estimated 100 billion neurons, with trillions of synapses. Scientists will need to find ways to store, annotate, and mine the volumes of data they create, and to meld information about connectivity with findings about the molecular and physiological characteristics of neurons in the circuits. But now, at least, they have a key tool with which to begin the massive effort of creating a wiring diagram of the brain.


Kevin Lynch

SOFTWARE

OFFLINE WEB APPLICATIONS

Kevin Lynch believes that computing applications will become more powerful when they take advantage of both the browser and the desktop. *By Erica Naone*

Web-based computer programs, unlike their desktop counterparts, are always up to date and are instantly available, no matter where the user is or what operating system she's running. That's why cloud computing—so called because it involves software that resides in the "clouds" of the Internet—has caused a "tidal shift in how people are actually creating software," says Kevin Lynch, chief software architect at Adobe Systems. (For a review of Nicholas Carr's new book on cloud computing, see "The Digital Utility," p. 92.) But cloud computing has drawbacks: users give up the ability to save data to their own hard drives, to drag and drop items between applications, and to receive notifications, such as appointment reminders, when the browser window is closed.

So while many companies have rushed to send users to the clouds, Lynch and his team have been planning the return trip. With the system they're developing, the Adobe Integrated Runtime (AIR), programmers can use Web technologies to build desktop applications that people can run online or off.

The project is rooted in Lynch's recognition of both the benefits and the limitations of the move from desktop to Web. He envisioned hybrid applications that would allow users to take simultaneous advantage of the Internet and their own machines' capabilities. Lynch's team started work on the concept in 2002 and launched AIR in beta last June.

AIR is a "runtime environment," an extra layer of software that allows the same program to run on different operating systems and hardware. (Java is another example.) With AIR, developers can use Web technologies such as HTML and Flash to write software for the desktop. Users won't have to seek out AIR to enjoy its benefits; they'll be prompted to download it along with the first AIR applications they want to use.

The Adobe team chose to base the system on HTML and Flash for several reasons, Lynch says. First, it makes it easy for desktop applications to swap content with websites: for example, information from a website can be pulled into an AIR application with its formatting intact. Second, it should simplify development, encouraging a broader range of applications. Programmers can easily rebuild existing Web applications to work on the desktop. And in the same way that Web-based applications can be built once and will then run on any device with a browser, an application built on AIR will run on any machine that has AIR installed. (Adobe currently offers versions for Windows and Macintosh and is developing versions for Linux and mobile devices.)

Adobe is already working with partners to demonstrate AIR's capabilities. One example: the popular auction site eBay has released a beta AIR-based application called eBay Desktop. Designed to improve the

TOBY BURDITT

WHO
Kevin Lynch, Adobe Systems

DEFINITION
Offline Web applications, developed using Web technologies such as HTML and Flash, can take advantage of the resources of a user's computer as well as those of the Internet.

IMPACT
Developers can quickly and cheaply build full-fledged desktop applications that are usable in a broad range of devices and operating systems.

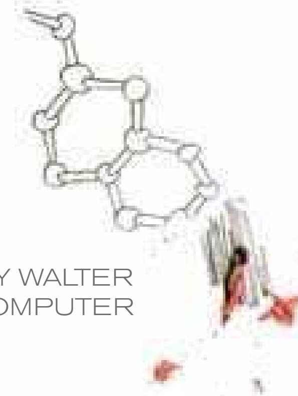
CONTEXT
Adobe will release AIR early this year; companies such as eBay, AOL, and Anthropologie have built applications using early versions of the software. Google is working on a competing platform called Gears.

customer's bidding experience, the application itself retrieves and displays content about eBay auctions rather than relying on a browser. It also takes advantage of the processing power of the user's computer to provide search tools more powerful than those on the website. For example, it can scan search results for related keywords—a process that product manager Alan Lewis says works better on the desktop because the application can store and quickly access lots of relevant information on the user's computer. The program also uses desktop alerts to notify users when someone bids on auctions they are following. AIR enabled the company to create a customized user interface, without constraints imposed by the browser's design and controls.

Lynch says that AIR was a response to the Web's evolution into a more interactive medium. The browser, he notes, was created for "the Web of pages"; while developers have stretched what can be done with it, Lynch sees the need for an interface more appropriate to the Web of software that people use today. AIR, he hopes, will be just that.

MIKE PERRY

HARDWARE



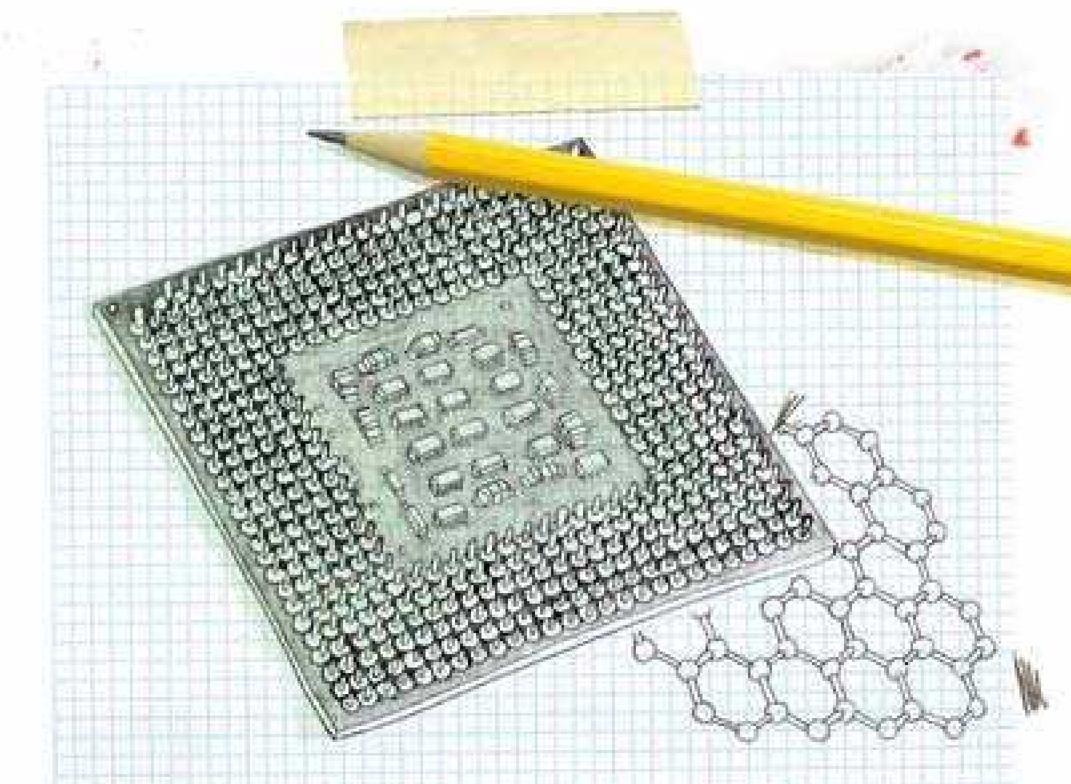
Graphene Transistors

A NEW FORM OF CARBON BEING PIONEERED BY WALTER DE HEER COULD LEAD TO SPEEDY, COMPACT COMPUTER PROCESSORS. *BY KEVIN BULLIS*

The remarkable increases in computer speed over the last few decades could be approaching an end, in part because silicon is reaching its physical limits. But this past December, in a small Washington, DC, conference room packed to overflowing with an audience drawn largely from the semiconductor industry, Georgia Tech physics professor Walter de Heer described his latest work on a surprising alternative to silicon that could be far faster. The material: graphene, a seemingly unimpressive substance found in ordinary pencil lead.

Theoretical models had previously predicted that graphene, a form of carbon consisting of layers one atom thick, could be made into transistors more than a hundred times as fast as today's silicon transistors. In his talk, de Heer reported making arrays of hundreds of graphene transistors on a single chip. Though the transistors still fall far short of the material's ultimate promise, the arrays, which were fabricated in collaboration with MIT's Lincoln Laboratory, offer strong evidence that graphene could be practical for future generations of electronics.

Today's silicon-based computer processors can perform only a certain number of operations per second without overheating. But electrons move through graphene with almost no resistance, generating little heat. What's more, graphene is itself a good thermal conductor, allowing heat to dissipate quickly. Because of



these and other factors, graphene-based electronics could operate at much higher speeds. "There's an ultimate limit to the speed of silicon–you can only go so far, and you cannot increase its speed any more," de Heer says. Right now silicon is stuck in the gigahertz range. But with graphene, de Heer says, "I believe we can do a terahertz–a factor of a thousand over a gigahertz. And if we can go beyond, it will be very interesting."

Besides making computers faster, graphene electronics could be useful for communications and imaging technologies that require ultrafast transistors. Indeed, graphene is likely to find its first use in high-frequency applications such as terahertz-wave imaging, which can be used to detect hidden weapons. And speed isn't graphene's only advantage. Silicon can't be carved into pieces smaller than about 10 nanometers without losing its attractive electronic properties. But the basic physics of graphene remain the same–and in some ways its electronic properties actually improve–in pieces smaller than a single nanometer.

Interest in graphene was sparked by research into carbon nanotubes as potential successors to silicon. Carbon nanotubes, which are essentially sheets of graphene rolled up into cylinders, also have excellent electronic properties that could lead to ultrahigh-performance electronics. But nanotubes have to be carefully sorted and positioned in order to produce complex circuits, and good ways to do this haven't been developed. Graphene is far easier to work with.

In fact, the devices that de Heer announced in December were carved into graphene using techniques very much like those used to manufacture silicon chips today. "That's why industry people are looking at what we're doing," he says. "We can pattern graphene using basically the same methods we pattern silicon with. It doesn't look like a science project. It looks like technology to them."

Graphene hasn't always looked like a promising electronic material. For one thing, it doesn't naturally exhibit the type of switching behavior required for computing. Semiconductors such as silicon can conduct electrons in one state, but they can also be switched to a state of very low conductivity, where they're essentially turned off. By contrast, graphene's conductivity can be changed slightly, but it can't be turned off. That's okay in certain applications, such as high-frequency transistors for imaging and communications. But such transistors would be too inefficient for use in computer processors.

In 2001, however, de Heer used a computer model to show that if graphene could be fashioned into very narrow ribbons, it would begin to behave like a semiconductor. (Other researchers, he learned later, had already made similar observations.) In practice, de Heer has not yet been able to fabricate graphene ribbons narrow enough to behave as predicted. But two other methods have been shown to have similar promise: chemically modifying graphene and putting a layer of graphene on top of certain other substrates. In his presentation in Washington, de Heer described how modifying graphene ribbons with oxygen can induce semiconducting behavior. Combining these different techniques, he believes, could produce the switching behavior needed for transistors in computer processors.

Meanwhile, the promise of graphene electronics has caught the semiconductor industry's attention. Hewlett-Packard, IBM, and Intel (which has funded de Heer's work) have all started to investigate the use of graphene in future products.

WHO
Walter de Heer, Georgia Tech

DEFINITION
Transistors based on graphene, a carbon material one atom thick, could have extraordinary electronic properties.

IMPACT
Initial applications will be in ultrahigh-speed communications chips, with computer processors to follow.

CONTEXT
A number of academic researchers and several electronics companies are studying graphene-based electronics.

SENSORS

ATOMIC MAGNETOMETERS

John Kitching's tiny magnetic-field sensors will take MRI where it's never gone before.
By Katherine Bourzac

Magnetic fields are everywhere, from the human body to the metal in a buried land mine. Even molecules such as proteins generate their own distinctive magnetic fields. Both magnetic resonance imaging (MRI), which yields stunningly detailed images of the body, and nuclear magnetic resonance spectroscopy (NMR), which is used to study proteins and other compounds such as petroleum, rely on magnetic information. But the sensors currently used to detect these faint but significant magnetic fields all have disadvantages. Some are portable and cheap but not very sensitive; others are highly sensitive but stationary, expensive, and power-hungry.

Now John Kitching, a physicist at the National Institute of Standards and Technology in Boulder, CO, is developing tiny, low-power magnetic sensors almost as sensitive as their big, expensive counterparts. About the size of a fat grain of rice, the sensors are called atomic magnetometers. Kitching hopes that they will one day be incorporated into everything from portable MRI machines to faster and cheaper detectors for unexploded bombs.

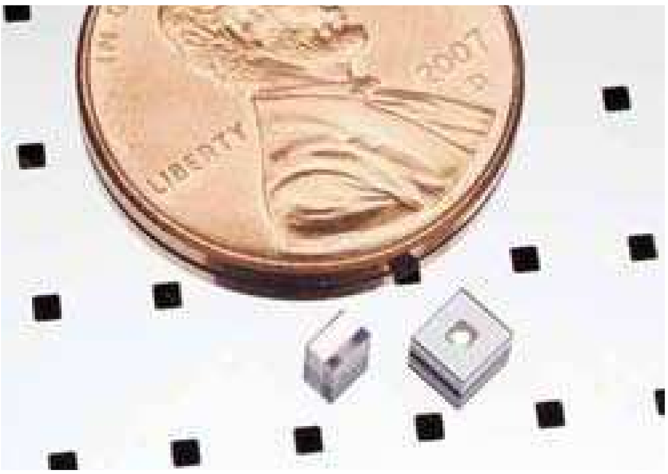
The tiny sensors have three key components, stacked vertically on top of a silicon chip. An off-the-shelf infrared laser and an

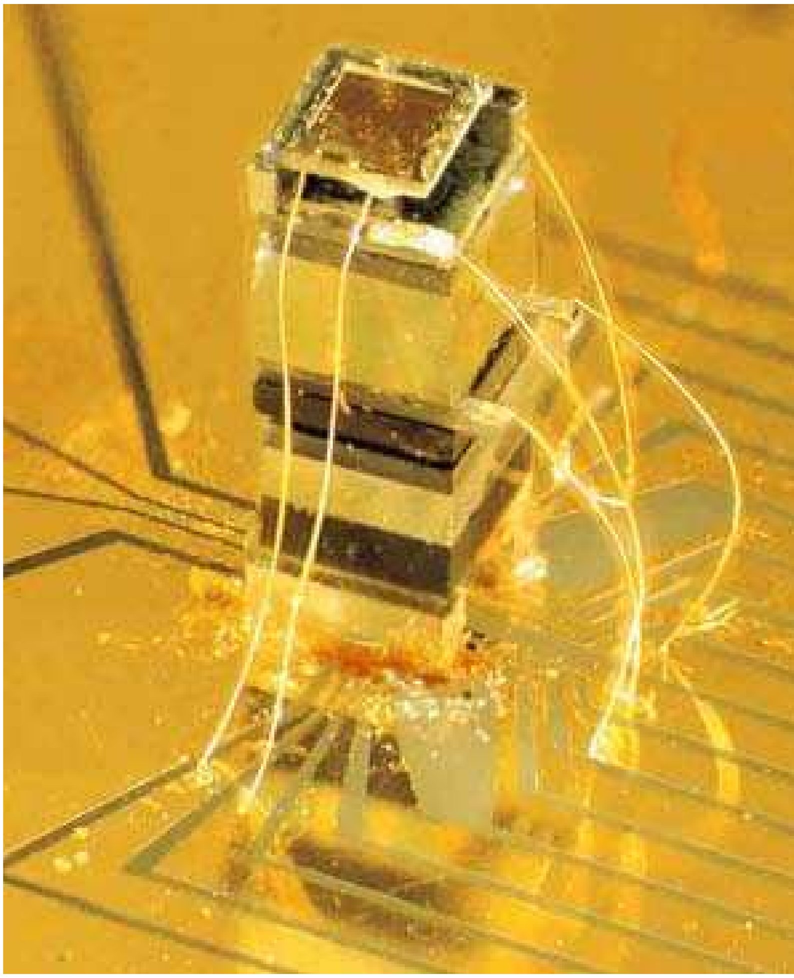
WHO
John Kitching, U.S. National Institute of Standards and Technology

DEFINITION
Miniaturized atomic magnetometers the size of a grain of rice require little power and are sensitive to very weak magnetic fields.

IMPACT
Tiny, inexpensive magnetometers could lead to portable MRI machines, tools for detecting buried explosive devices, and ways to evaluate mineral deposits remotely.

CONTEXT
Kitching's miniaturization of these sensors could bring them into much wider use in the coming decade.





SHRINKING SENSORS To build their tiny magnetic-field sensors, NIST physicists first punch holes in a silicon wafer, then slice the wafer into chips (top left). One side of the chip is bonded to glass; then the researchers inject cesium atoms into the hole with a small glass syringe (middle left). Next, the researchers seal the hole with another piece of glass, creating a tiny box (bottom left). The completed magnetometer consists of a small infrared laser (glued to a gold-coated plate), the cesium-filled cell, and a light detector (above).

JIM YOST; COURTESY OF JOHN KITCHING

infrared photodetector sandwich a glass-and-silicon cube filled with vaporized cesium atoms. In the absence of a magnetic field, the laser light passes straight through the cesium atoms. In the presence of even very weak magnetic fields, though, the atoms' alignment changes, allowing them to absorb an amount of light proportional to the strength of the field. This change is picked up by the photodetector. "It's a simple configuration with extremely good sensitivity," Kitching says.

Atomic magnetometers have been around for about 50 years; most have large, sensitive vapor cells, about the size of soda cans, made using glassblowing techniques. The most sensitive of these can detect fields on the order of a femtotesla—about one-fifty-billionth the strength of Earth's magnetic field. Kitching's innovation was to shrink the vapor cell to a volume of only a few cubic millimeters, decreasing power usage while keeping performance comparable.

Working with five other physicists, Kitching makes the vapor cells using micromachining techniques. They begin by using a combination of lithography and chemical etching to punch square holes three millimeters across into a silicon wafer. Then they clamp the silicon to a slip of glass and create a bond using high heat and a voltage, turning the square hole into a topless box with a glass bottom.

Inside a vacuum chamber, they use a tiny glass syringe to fill the box with vaporized cesium atoms; then they seal the box with another slip of glass at high heat. (This must be done in a vacuum because cesium reacts vigorously with water and oxygen.) Next, the physicists mount the finished vapor cell on a chip, along with the infrared laser and the photodetector. They pass a current through thin conductive films on the top and bottom of the cell to produce heat, which keeps the cesium atoms vaporized.

Kitching currently builds magnetometers a few at a time in the lab, but he has designed them with bulk manufacturing in mind. Many copies of each component are carved out simultaneously from a single silicon wafer. Several wafers, each containing multiple copies of a different component, could be layered one on top of the other. Then the stack could be sliced into multiple magnetometers.

Made in this inexpensive way, the low-power sensors could be set into portable, battery-powered imaging arrays. Such arrays could easily map out the strength and extent of magnetic fields; the more sensors in an array, the more information it can provide about an object's location and shape. Soldiers, for example, could use such arrays to find unexploded bombs and improvised explosive devices more quickly and cheaply.

The tiny sensors could also revolutionize MRI and NMR. Both technologies rely on powerful, cumbersome, expensive magnets that require costly cooling systems. Because Kitching's sensors can detect very weak magnetic fields, MRI and NMR machines incorporating them might be able to get good pictures using a magnet that's much weaker—and therefore smaller and cheaper.

As a result, MRI could become more widely available. And for the first time, doctors could use it to examine patients with pacemakers or other metallic implants that can't be exposed to powerful magnets. Portable systems might even be developed for use in ambulances or on battlefields. And NMR could move from the lab into the field, where it could help oil and mining companies assess promising underground deposits.

Kitching and his colleagues recently showed that the sensors can measure NMR signals produced by water. Much remains to be done, Kitching says, before the devices can resolve faint signals from multiple chemical structures—distinguishing, say, between several possible trace contaminants in a water sample. Likewise, portable MRI machines will take some work. But with Kitching's miniaturized magnetometers, the challenge will shift from gathering magnetic information to interpreting it.

ELECTRICITY

Wireless Power

PHYSICIST MARIN SOLJAČIĆ IS WORKING TOWARD A WORLD OF WIRELESS ELECTRICITY. *BY JENNIFER CHU*

In the late 19th century, the realization that electricity could be coaxed to light up a bulb prompted a mad dash to determine the best way to distribute it. At the head of the pack was inventor Nikola Tesla, who had a grand scheme to beam electricity around the world. Having difficulty imagining a vast infrastructure of wires extending into every city, building, and room, Tesla figured that wireless was the way to go. He drew up plans for a tower, about 57 meters tall, that he claimed would transmit power to points kilometers away, and even started to build one on Long Island. Though his team did some tests, funding ran out before the tower was completed. The promise of airborne power faded rapidly as the industrial world proved willing to wire up.

Then, a few years ago, Marin Soljačić, an assistant professor of physics at MIT, was dragged out of bed by the insistent beeping of a cell phone. "This one didn't want to stop until you plugged it in for charging," says Soljačić. In his exhausted state, he wished the phone would just begin charging itself as soon as it was brought into the house.

So Soljačić started searching for ways to transmit power wirelessly. Instead of pursuing a long-distance scheme like Tesla's, he decided to look for midrange power transmission methods that could charge—or even power—portable devices such as cell phones, PDAs, and laptops. He considered using radio waves, which effectively send information through the air, but found that most of their energy would be lost in space. More-targeted methods like lasers require a clear line of sight—and could have harmful effects on anything in their way. So Soljačić sought a method that was both efficient—able to directly power receivers without dissipating energy to the surroundings—and safe.

He eventually landed on the phenomenon of resonant coupling, in which two objects tuned to the same frequency exchange energy strongly but interact only weakly with other objects. A classic example is a set of wine glasses, each filled to a different level so that it vibrates at a different sound frequency. If a singer hits a pitch that matches the frequency of one glass, the glass might absorb so much acoustic energy that it will shatter; the other glasses remain unaffected.

Soljačić found magnetic resonance a promising means of electricity transfer because magnetic fields travel freely through air yet have little effect on the environment or, at the appropriate frequencies, on living beings. Working with MIT physics professors John Joannopoulos and Peter Fisher and three students, he devised a simple setup that wirelessly powered a 60-watt light bulb.

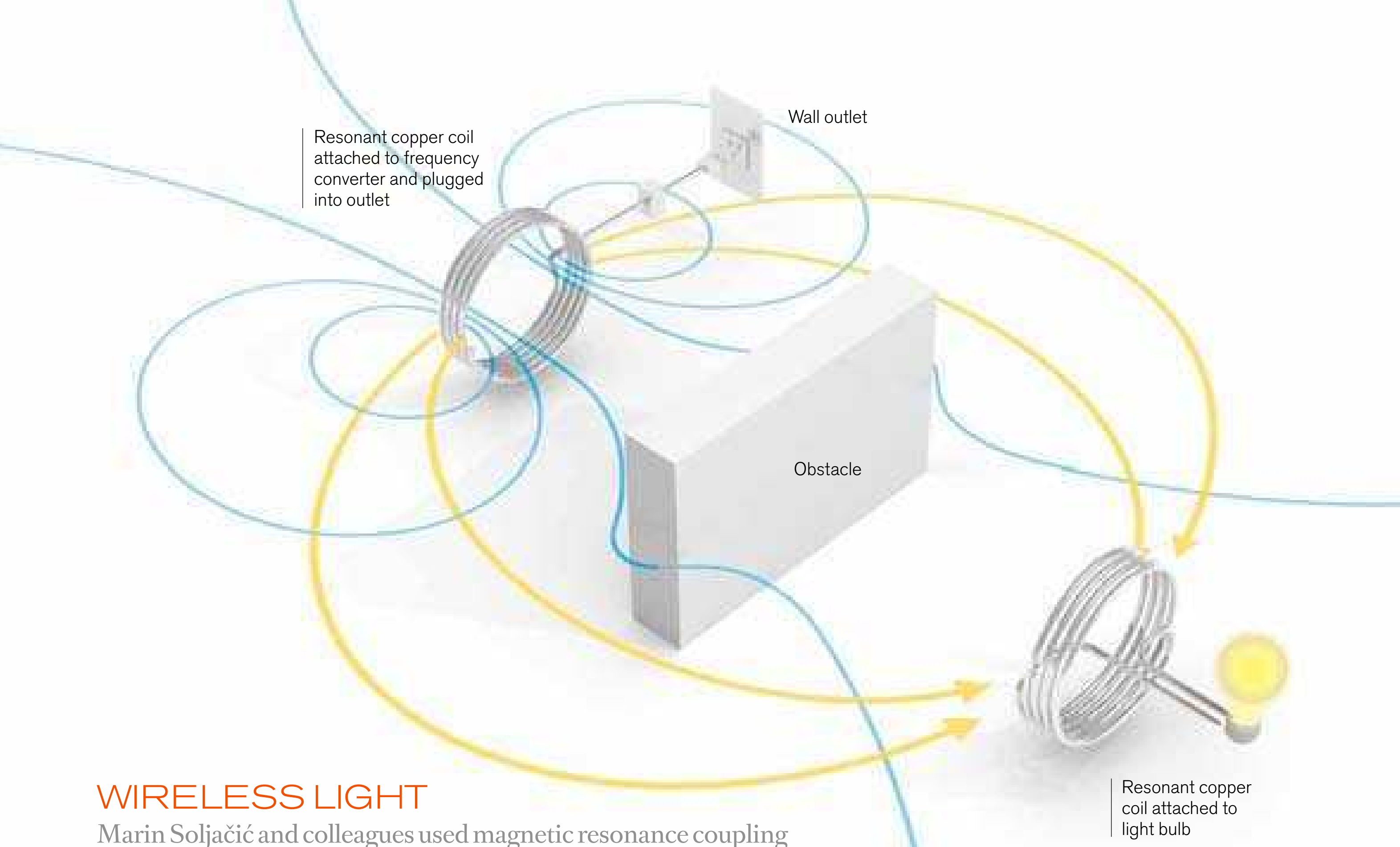
The researchers built two resonant copper coils and hung them from the ceiling, about two meters apart. When they plugged one coil into the wall, alternating current

WHO
Marin Soljačić, MIT

DEFINITION
Wireless power technology transmits electricity to devices without the use of cables.

IMPACT
Any low-power device, such as a cell phone, iPod, or laptop, could recharge automatically simply by coming within range of a wireless power source, eliminating the need for multiple cables—and perhaps, eventually, for batteries.

CONTEXT
Eliminating the power cord would make today's ubiquitous portable electronics truly wireless. A number of researchers and startups are making headway in this growing field.



WIRELESS LIGHT

Marin Soljačić and colleagues used magnetic resonance coupling to power a 60-watt light bulb. Tuned to the same frequency, two 60-centimeter copper coils can transmit electricity over a distance of two meters, through the air and around an obstacle.

flowed through it, creating a magnetic field. The second coil, tuned to the same frequency and hooked to a light bulb, resonated with the magnetic field, generating an electric current that lit up the bulb—even with a thin wall between the coils.

So far, the most effective setup consists of 60-centimeter copper coils and a 10-megahertz magnetic field; this transfers power over a distance of two meters with about 50 percent efficiency. The team is looking at silver and other materials to decrease coil size and boost efficiency. "While ideally it would be nice to have efficiencies at 100 percent, realistically, 70 to 80 percent could be possible for a typical application," says Soljačić.

Other means of recharging batteries without cords are emerging. Startups such as Powercast, Fulton Innovation, and WildCharge have begun marketing adapters and pads that allow consumers to wirelessly recharge cell phones, MP3 players, and other devices at home or, in some cases, in the car. But Soljačić's technique differs from these approaches in that it might one day enable devices to recharge automatically, without the use of pads, whenever they come within range of a wireless transmitter.

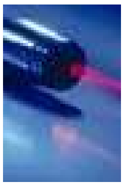
The MIT work has attracted the attention of consumer-electronics companies and the auto industry. The U.S. Department of Defense, which is funding the research, hopes it will also give soldiers a way to automatically recharge batteries. However, Soljačić remains tight-lipped about possible industry collaborations.

"In today's battery-operated world, there are so many potential applications where this might be useful," he says. "It's a powerful concept."

WIRELESS POWER TRANSFER

A few methods of wireless energy propagation:

RADIATIVE POWER is the transmission of energy via electromagnetic waves; the waves radiate away from the source at the speed of light. Familiar examples: sunlight, radio, TV, Wi-Fi.



DIRECTED RADIATION is the transmission of energy in focused beams; it is directional (and sometimes high power) and can cover long distances. Familiar example: laser pointer.

MAGNETIC INDUCTION uses magnetic fields to create a current between conductors; it works only over very short distances. Familiar example: electric toothbrush charger.

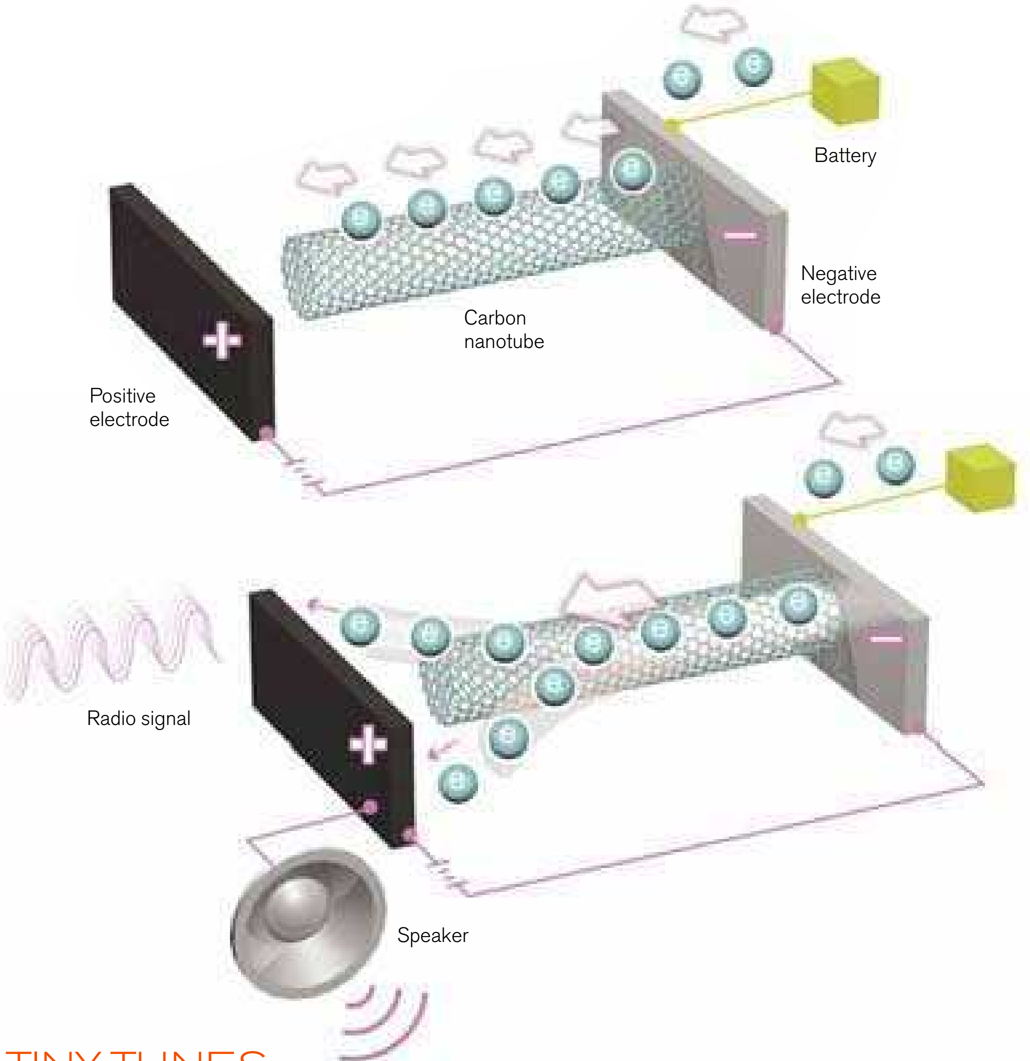
THE TESLA TOWER was designed to ionize the upper atmosphere, generating a wide-spanning current from which household antennas could draw power; it was supposed to work over long distances.

BRYAN CHRISTIE DESIGN; BETTMAN/CORBIS (TESLA TOWER)

NANOTECHNOLOGY

NANORADIO

Alex Zettl's tiny radios, built from nanotubes, could improve everything from cell phones to medical diagnostics. *By Robert F. Service*



TINY TUNES

A nanoradio is a carbon nanotube anchored to an electrode, with a second electrode just beyond its free end. When a voltage is applied between the electrodes, electrons flow from a battery through the nanotube, jumping off its tip to the positive electrode. A radio wave alternately attracts and repels the nanotube tip, causing it to vibrate in sync. When the tip is farther from the electrode, fewer electrons bridge the gap; the varying electrical signal recovers the audio signal encoded by the radio wave.

JOHN HERSEY

If you own a sleek iPod Nano, you've got nothing on Alex Zettl. The physicist at the University of California, Berkeley, and his colleagues have come up with a nanoscale radio, in which the key circuitry consists of a single carbon nanotube.

Any wireless device, from cell phones to environmental sensors, could benefit from nanoradios. Smaller electronic components, such as tuners, would reduce power consumption and extend battery life. Nanoradios could also steer wireless communications into entirely new realms, including tiny devices that navigate the bloodstream to release drugs on command.

Miniaturizing radios has been a goal ever since RCA began marketing its pocket-sized transistor radios in 1955. More recently, electronics manufacturers have made microscale radios, creating new products such as radio frequency identification (RFID) tags. About five years ago, Zettl's group decided to try to make radios even smaller, working at the molecular scale as part of an effort to create cheap wireless environmental sensors.

Zettl's team set out to miniaturize individual components of a radio receiver, such as the antenna and the tuner, which selects one frequency to convert into a stream of electrical pulses that get sent to a speaker. But integrating separate nanoscale components proved difficult. About a year ago, however, Zettl and his students had a eureka moment. "We realized that, by golly, one nanotube can do it all," Zettl says. "Within a matter of days, we had a functioning radio." The first two transmissions it received were "Layla" by Derek and the Dominos and "Good Vibrations" by the Beach Boys.

The Beach Boys song was an apt choice. Zettl's nano receiver works by translating the electromagnetic oscillations of a radio wave into the mechanical vibrations of a nanotube, which are in turn converted into a stream of electrical pulses that reproduce the original radio signal. Zettl's team anchored a nanotube to a metal electrode, which is wired to a battery. Just beyond the nanotube's free end is a second metal electrode. When a voltage is applied between the electrodes, electrons flow from the battery through the first electrode and the nanotube and then jump from the nanotube's tip across the tiny gap to the second electrode. The nanotube—now negatively charged—is able to "feel" the oscillations of a passing radio wave, which (like all electromagnetic waves) has both an electrical and a magnetic component.

Those oscillations successively attract and repel the tip of the tube, making the tube vibrate in sync with the radio wave. As the tube is vibrating, electrons continue to spray out of its tip. When the tip is farther from the second electrode, as when the tube bends to one side,

WHO
Alex Zettl, University of California, Berkeley

DEFINITION
At the core of the nanoradio is a single molecule that can receive radio signals.

IMPACT
Tiny radio devices could improve cell phones and allow communication between tiny devices, such as environmental sensors.

CONTEXT
New nanotech tools are allowing researchers to fabricate very small devices. The nanoradio is one of the latest.

fewer electrons make the jump across the gap. The fluctuating electrical signal that results reproduces the audio information encoded onto the radio wave, and it can be sent to a speaker.

The next step for Zettl and his colleagues is to make their nanoradios send out information in addition to receiving it. But Zettl says that won't be hard, since a transmitter is essentially a receiver run in reverse.

Nano transmitters could open the door to other applications as well. For instance, Zettl suggests that nanoradios attached to tiny chemical sensors could be implanted in the blood vessels of patients with diabetes or other diseases. If the sensors detect an abnormal level of insulin or some other target compound, the transmitter could then relay the information to a detector, or perhaps even to an implanted drug reservoir that could release insulin or another therapeutic on cue. In fact, Zettl says that since his paper on the nanotube radio came out in the journal *Nano Letters*, he's received several calls from researchers working on radio-based drug delivery vehicles. "It's not just fantasy," he says. "It's active research going on right now."

HARDWARE

Probabilistic Chips

KRISHNA PALEM THINKS INTRODUCING A LITTLE UNCERTAINTY INTO COMPUTER CHIPS COULD EXTEND BATTERY LIFE IN MOBILE DEVICES—AND MAYBE THE DURATION OF MOORE'S LAW, TOO. *BY ERIKA JONIETZ*

Krishna Palem is a heretic. In the world of microchips, precision and perfection have always been imperative. Every step of the fabrication process involves testing and retesting and is aimed at ensuring that every chip calculates the exact answer every time. But Palem, a professor of computing at Rice University, believes that a little error can be a good thing.

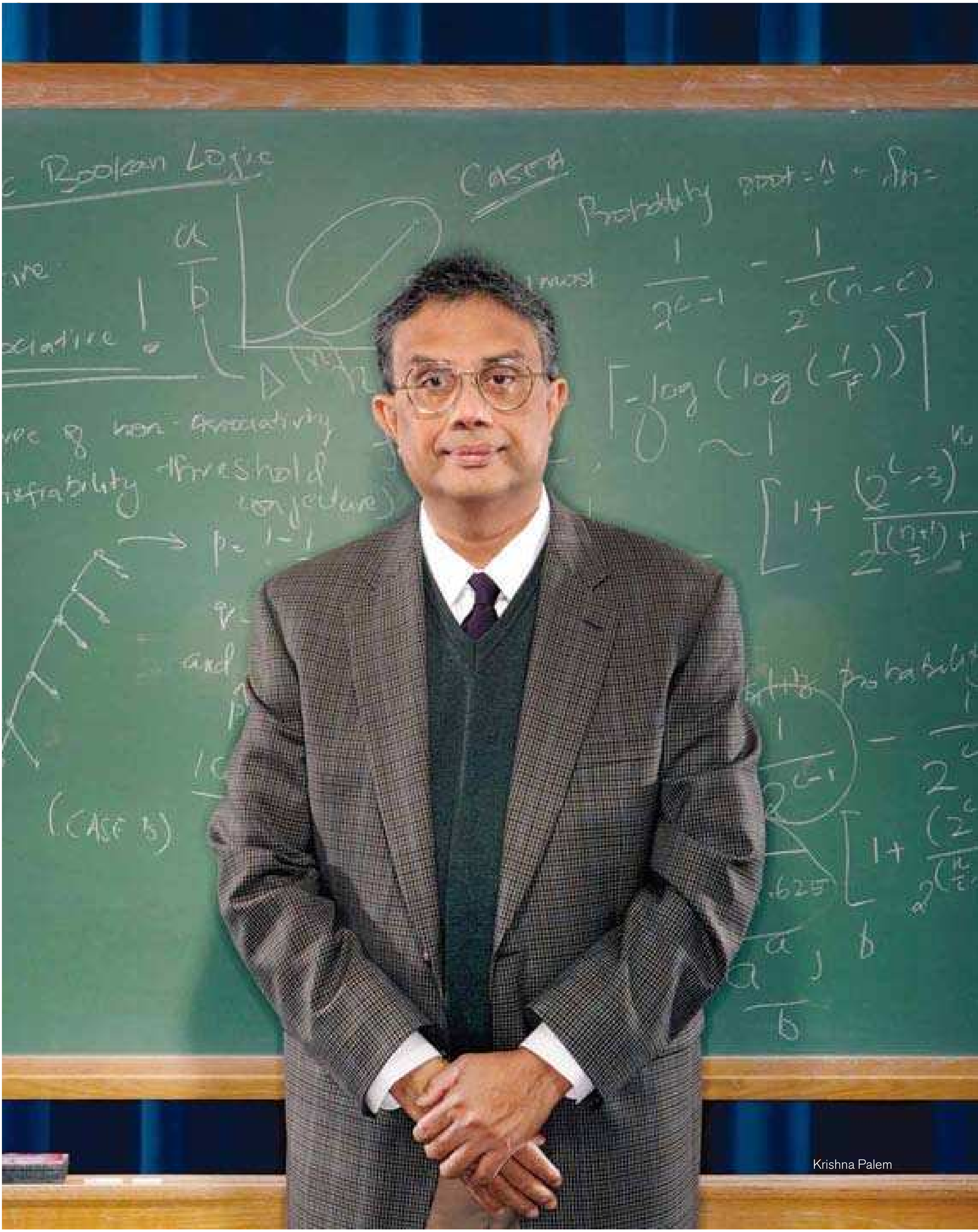
Palem has developed a way for chips to use significantly less power in exchange for a small loss of precision. His concept carries the daunting moniker "probabilistic complementary metal-oxide semiconductor technology"—PCMOS for short. Palem's premise is that for many applications—in particular those like audio or video processing, where the final result isn't a number—maximum precision is unnecessary. Instead, chips could be designed to produce the correct answer sometimes, but only come close the rest of the time. Because the errors would be small, so would their effects: in essence, Palem believes that in computing, close enough is often good enough.

Every calculation done by a microchip depends on its transistors' registering either a *1* or a *0* as electrons flow through them in response to an applied voltage. But electrons move constantly, producing electrical "noise." In order to overcome noise and ensure that their transistors register the correct values, most chips run at a relatively high voltage. Palem's idea is to lower the operating voltage of parts of a chip—specifically, the logic circuits that calculate the least significant bits, such as the *3* in the number *21,693*. The resulting decrease in signal-to-noise ratio means those circuits would occasionally arrive at the wrong answer, but engineers can calculate the probability of getting the right answer for any specific voltage. "Relaxing the probability of correctness even a little bit can produce significant savings in energy," Palem says.

Within a few years, chips using such designs could boost battery life in mobile devices such as music players and cell phones. But in a decade or so, Palem's ideas could have a much larger impact. By then, silicon transistors will be so small that engineers won't be able to precisely control their behavior: the transistors will be inherently probabilistic. Palem's techniques could then become important to the continuation of Moore's Law, the exponential increase in transistor density—and thus in computing power—that has persisted for four decades.

When Palem began working on the idea around 2002, skepticism about the principles behind PCMOS was "pretty universal," he says. That changed in 2006. He and his students simulated a PCMOS circuit that would be part of a chip for processing video, such as streaming video in a cell phone, and compared it with the performance of existing chips. They presented the work at a technical conference, and in a show of hands, much of the audience couldn't discern any difference in picture quality.

Applications where the limits of human perception reduce the need for precision are perfectly suited to PCMOS designs, Palem says. In cell phones, laptop computers, and other mobile devices, graphics and sound processing consume a significant



Krishna Palem

proportion of the battery power; Palem believes that PCMOS chips might increase battery life as much as tenfold without compromising the user's experience.

PCMOS also has obvious applications in fields that employ probabilistic approaches, such as cryptography and machine learning. Algorithms used in these fields are typically designed to arrive quickly at an approximate answer. Since PCMOS chips do the same thing, they could achieve in hardware what must be done with software today—with a significant gain in both energy efficiency and speed. Palem envisions devices that use one or more PCMOS coprocessors to handle specialized tasks, such as encryption, while a traditional chip assists with other computing chores.

Palem and his team have already built and started testing a cryptography engine. They are also designing a graphics engine and a chip that people could use to adjust the power consumption and performance of their cell phones: consumers might choose high video or call quality and consume more power or choose lower quality and save the battery. Palem is discussing plans for one or more startup companies to commercialize such PCMOS chips. Companies could launch as early as next year, and products might be available in three or four years.

As silicon transistors become smaller, basic physics means they will become less reliable, says Shekhar Borkar, director of Intel's Microprocessor Technology Lab. "So what you're looking at is having a probability of getting the result you wanted," he says. In addition to developing hardware designs, Palem has created a probabilistic analogue to the Boolean algebra that is at the core of computational logic circuits; it is this probabilistic logic that Borkar believes could keep Moore's Law on track. Though he says that much work remains to be done, Borkar says Palem's research "has a very vast applicability in any digital electronics."

If Palem's research plays out the way the optimists believe it will, he may have the rebel's ultimate satisfaction: seeing his heresy become dogma.

WHO
Krishna Palem, Rice University

DEFINITION
PCMOS is a microchip design technology that allows engineers to trade a small degree of accuracy in computation for substantial energy savings.

IMPACT
In the short term, PCMOS designs could significantly increase battery life in mobile devices; in a decade, the theories behind PCMOS may need to be invoked if Moore's Law is to continue to hold.

CONTEXT
Palem and his collaborators have begun building test chips for specific applications; Palem is working on plans for startup companies to commercialize the technology.

BRENT HUMPHREYS

SOFTWARE

MODELING SURPRISE

Combining massive quantities of data, insights into human psychology, and machine learning can help humans manage surprising events, says Eric Horvitz. *By M. Mitchell Waldrop*

Much of modern life depends on forecasts: where the next hurricane will make landfall, how the stock market will react to falling home prices, who will win the next primary. While existing computer models predict many things fairly accurately, surprises still crop up, and we probably can't eliminate them. But Eric Horvitz, head of the Adaptive Systems and Interaction group at Microsoft Research, thinks we can at least minimize them, using a technique he calls "surprise modeling."

Horvitz stresses that surprise modeling is not about building a technological crystal ball to predict what the stock market will do tomorrow, or what al-Qaeda might do next month. But, he says, "We think we can apply these methodologies to look at the kinds of things that have surprised us in the past and then model the kinds of things that may surprise us in the future." The result could be enormously useful for decision makers in fields that range from health care to military strategy, politics to financial markets.

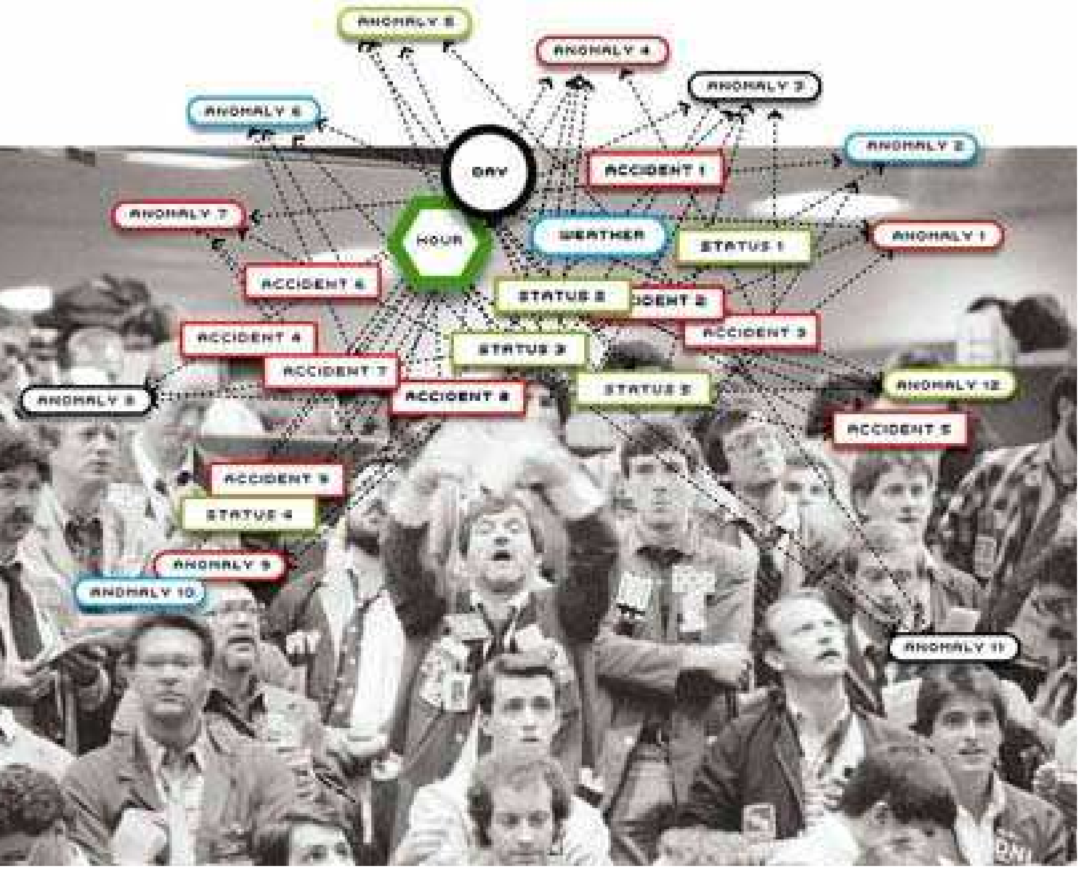
Granted, says Horvitz, it's a far-out vision. But it's given rise to a real-world application: SmartPhlow, a traffic-forecasting service that Horvitz's group has been developing and testing at Microsoft since 2003.

SmartPhlow works on both desktop computers and Microsoft PocketPC devices. It depicts traffic conditions in Seattle, using a city map on which backed-up highways appear red and those with smoothly flowing traffic appear green. But that's just the beginning. After all, Horvitz says, "most people in Seattle already know that such-and-such a highway is a bad idea in rush hour." And a machine that constantly tells you what you already know is just irritating. So Horvitz and his team added software that alerts users only to surprises—the times when the traffic develops a bottleneck that most people wouldn't expect, say, or when a chronic choke point becomes magically unclogged.

But how? To monitor surprises effectively, says Horvitz, the machine has to have both knowledge—a good cognitive model of what humans find surprising—and foresight: some way to predict a surprising event in time for the user to do something about it.

Horvitz's group began with several years of data on the dynamics and status of traffic all through Seattle and added information about anything that could affect such patterns: accidents, weather, holidays, sporting events, even visits by high-profile officials. Then, he says, for dozens of sections of a given road, "we divided the day into 15-minute segments and used the data to compute a probability distribution for the traffic in each situation."

That distribution provided a pretty good model of what knowledgeable drivers expect from the region's traffic, he says. "So then we went back through



the data looking for things that people wouldn't expect—the places where the data shows a significant deviation from the averaged model." The result was a large database of surprising traffic fluctuations.

Once the researchers spotted a statistical anomaly, they backtracked 30 minutes, to where the traffic seemed to be moving as expected, and ran machine-learning algorithms to find subtleties in the pattern that would allow them to predict the surprise. The algorithms are based on Bayesian modeling techniques, which calculate the probability, based on prior experience, that something will happen and allow researchers to subjectively weight the relevance of contributing events *(see TR10: "Bayesian Machine Learning," February 2004)*.

The resulting model works remarkably well, Horvitz says. When its parameters are set so that its false-positive rate shrinks to 5 percent, it still predicts about half of the surprises in Seattle's traffic system. If that doesn't sound impressive, consider that it tips drivers off to 50 percent more surprises than they would otherwise know about. Today, more than 5,000 Microsoft employees have this "surprise machine" loaded on their smart phones, and many have customized it to reflect their own preferences.

WHO
Eric Horvitz, Microsoft Research

DEFINITION
Surprise modeling combines data mining and machine learning to help people do a better job of anticipating and coping with unusual events.

IMPACT
Although research in the field is preliminary, surprise modeling could aid decision makers in a wide range of domains, such as traffic management, preventive medicine, military planning, politics, business, and finance.

CONTEXT
A prototype that alerts users to surprises in Seattle traffic patterns has proved effective in field tests involving thousands of Microsoft employees. Studies investigating broader applications are now under way.

Horvitz's group is working with Microsoft's traffic and routing team on the possibility of commercializing aspects of SmartPhlow. And in 2005 Microsoft announced that it had licensed the core technology to Inrix of Kirkland, WA, which launched the Inrix Traffic application for Windows Mobile devices last March. The service offers traffic predictions, several minutes to five days in advance, for markets across the United States and England.

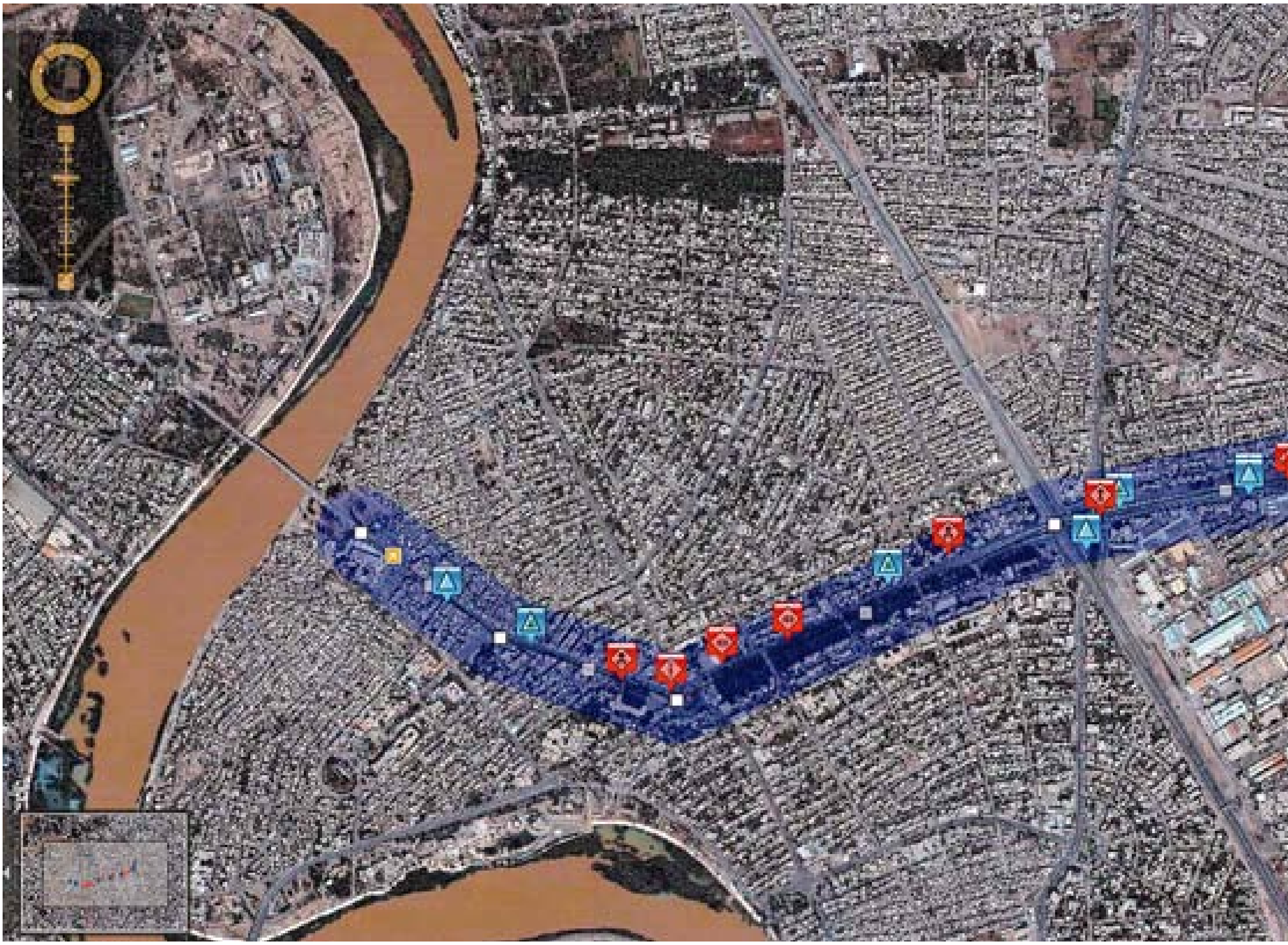
Although none of the technologies involved in SmartPhlow is entirely new, notes Daphne Koller, a probabilistic-modeling and machine-learning expert at Stanford University, their combination and application are unusual. "There has been a fair amount of work on anomaly detection in large data sets to detect things like credit card fraud or bioterrorism," she says. But that work emphasizes the detection of present anomalies, she says, not the prediction of events that may occur in the near future. Additionally, most predictive models disregard statistical outliers; Horvitz's specifically tracks them. The thing that makes his approach unique, though, is his focus on the human factor, Koller says: "He's explicitly trying to model the human cognitive process."

The question is how wide a range of human activities can be modeled this way. While the algorithms used in SmartPhlow are, of necessity, domain specific, Horvitz is convinced that the overall approach could be generalized to many other areas. He has already talked with political scientists about using surprise modeling to predict, say, unexpected conflicts. He is also optimistic that it could predict, for example, when an expert would be surprised by changes in housing prices in certain markets, in the Dow Jones Industrial Average, or in the exchange rate of a currency. It could even predict business trends. "Over the past few decades, companies have died because they didn't foresee the rise of technologies that would lead to a major shift in the competitive landscape," he says.

Most such applications are a long way off, Horvitz concedes. "This is a longer-term vision. But it's very important, because it's at the foundation of what we call wisdom: understanding what we don't know."

WWW To hear the TR10 researchers explain their technologies, go to **technologyreview.com/tr10.**

PHOTO: BETTMAN/CORBIS; GRAPHICS: JOHN HERSEY

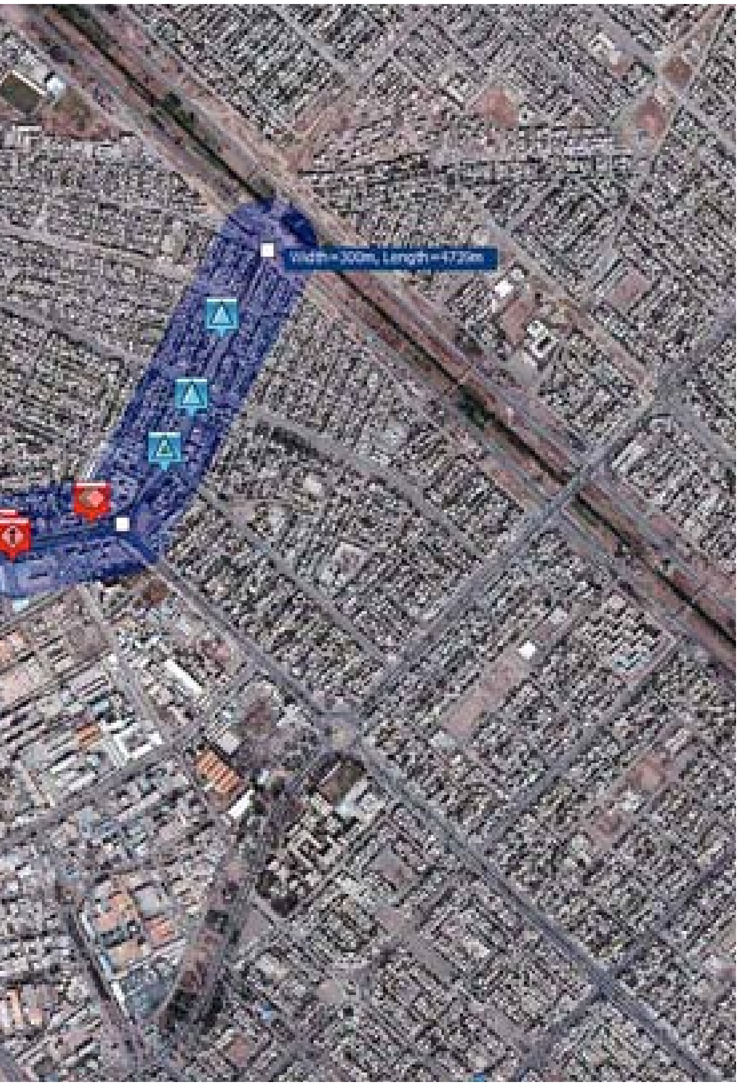


A Technology Surges

IN IRAQ, SOLDIERS CONDUCTING FRONTLINE STREET PATROLS FINALLY GET SOFTWARE TOOLS THAT LET THEM SHARE FINDINGS AND PLAN MISSIONS.

By DAVID TALBOT

First Lieutenant Brian Slaughter wanted his comrades to learn from the insurgent attack that could have killed him on May 21, 2004. Before dawn, the 30-year-old had been leading 12 men in three armored Humvees along a canal in Baghdad's al-Dora district when a massive blast from an improvised explosive device (IED) lifted his vehicle off the ground. Concealed attackers followed with a volley of rocket-propelled grenades and machine-gun fire. But the IED had been buried too deep to kill, a second IED detonated too early to hit the patrol, and a third failed to explode. When the brief battle ended, two insurgents were dead, and ten were prisoners. On the American side, one man had been injured, with a bullet to the leg.



BAGHDAD ROUTE PLANNER A new map-based application allows patrol leaders in Iraq to learn about city landmarks and past events and enter new data. In this mock-up provided by DARPA (the map does not reflect actual events), the purple line shows a possible Baghdad patrol route. Past events in a 300-meter buffer are noted. Hostile actions, such as IED attacks or shootings, appear as various red icons; friendly actions, such as visits to schools, appear as blue icons. Clicking the icons brings up text, photos, even videos.

COURTESY OF DARPA

Slaughter knew that information about the encounter could help his fellow soldiers—especially green replacements arriving from Fort Stewart, GA—avoid getting killed or maimed. It might help them capture insurgents, too. So when dawn broke, he explored the blast site with a digital camera. He took pictures of the mound of brown earth concealing the still-unexploded second IED, and of a red-and-white detonator cord that led to the device. He took pictures of a berm and a copse of palm trees that had concealed the enemy. He took pictures of the improvised weapon: a 155-millimeter artillery shell that had been drilled out and fitted with a fuse.

But his attempts to share the information ran into a technological roadblock. Back at Camp Falcon, a facility on the southern outskirts of Baghdad that's one of a handful of so-called forward operating bases around the city, he typed up a document in Microsoft Word and appended his photos. The report went to a battalion intelligence officer swamped by two or three dozen such reports daily. The intelligence officer's summaries went into a database called ASAS-L. A product of Cold War thinking, the database allows top commanders to monitor and coördinate troop movements—but it's not easily accessible to patrol leaders like Slaughter.

So for practical purposes, his report didn't exist. Even the version that stayed on his computer at Camp Falcon eventually vanished. "It went home with my unit. There was no server. No continuity. Nothing," he says. The pictures survive—on his laptop in Nashville, TN. He showed them to me, along with lots of other pictures that might have had some value to his fellow soldiers, including one of the smiling principal of a girls' school in Baghdad and one of an Iraqi translator—later killed, Slaughter says—interviewing someone who Slaughter says was believed to be an imam with ties to al-Qaeda in Iraq.

But the days of patrol leaders operating half-blind on the deadly streets of Iraq are drawing to a close. After a two-year rush program by the Pentagon's research arm, the U.S. Defense Advanced Research Projects Agency, or DARPA, troops are now getting what might be described as Google Maps for the Iraq counterinsurgency. There is nothing cutting-edge about the underlying technology: software that runs on PCs and taps multiple distributed databases. But the trove of information the system delivers is of central importance in the daily lives of soldiers.

The new technology—called the Tactical Ground Reporting System, or TIGR—is a map-centric application that junior officers (the young sergeants and lieutenants who command patrols) can study before going on patrol and add to upon returning. By clicking on icons and lists, they can see the locations of key buildings, like mosques, schools, and hospitals, and retrieve information such as location data on past attacks, geotagged photos of houses and other buildings (taken with cameras equipped with Global Positioning System technology), and photos of suspected insurgents and neighborhood leaders. They can even listen to civilian interviews and watch videos of past maneuvers. It is just the kind of information that soldiers need to learn about Iraq and its perils.

For some units, anyway, the database is becoming the technological fulcrum of the counterinsurgency. More than 1,500 junior officers—about a fifth of patrol leaders—are already using the technology, which was first deployed in early 2007. The first major unit to use it—the First Brigade Combat Team, First Cavalry Division—returned to the United States in late January. A few days before leaving Camp Taji, northwest of Baghdad, one soldier in

DATA CENTER The new software documents the fabric of life in Iraq. In this mock-up (which does not reflect accurate data), a Baghdad neighborhood is set off by a purple boundary, and places, people, and events are marked by color-coded icons. Soldiers can click the icons and scroll through lists for more information. For example, thumbnail photos showing the aftermath of an IED attack appear next to the list. Thousands of photos are stored in the application's database.

COURTESY OF DARPA

this unit, Major Patrick Michaelis—who had many better things to do—paused to write an effusive 1,000-word e-mail to *Technology Review*. He said that the technology had saved the lives of soldiers by allowing them to avoid IEDs, and that it enabled them to make better use of intelligence, capture insurgents, and improve their relationships with local people. "The ability ... to draw the route ... of your patrol that day and then to access the collective reports, media, analysis of the entire organization, is pretty powerful," Michaelis wrote. "It is a bit revolutionary from a military perspective when you think about it, using peer-based information to drive the next move. ... Normally we are used to our higher headquarters telling the patrol leader what he needs to think."

A GRANULAR ENVIRONMENT

The Pentagon has long talked about empowering soldiers with information. Some new networking technologies were deployed during the Iraq invasion, albeit with mixed results *(see "How Tech Failed in Iraq," November 2004)*. And back in the United States, the Pentagon has been pursuing multibillion-dollar R&D programs with names like Future Combat Systems. These programs anticipate a day when aircraft, ground vehicles, robots, and soldier-mounted sensors collect masses of information; new software makes sense of it all, detecting changes and identifying targets; and wireless networking technologies link fighting units and even individual soldiers, who might have digital displays mounted to their helmets. Such technologies are part of the military's long-term plan to introduce what is sometimes called "network-centric warfare."

Generally, however, these high-tech visions have not meant much to the soldiers and marines patrolling dangerous streets in Iraq. U.S. troops conduct more than 300 street patrols around the country every day; those patrols make up one of the war's principal fronts. But for the most part, the leaders of the patrols have found it difficult to access digital information about their routes. Intelligence dissemination was stuck for years in another era. "We have a tendency in the army and marines and air force to build systems, first of all, that are platform-centric [built to ride on, say, a tank or a plane] and second, to build them for the higher echelons," says Pat O'Neal, a retired brigadier general who acts as an advisor to DARPA—and whose son is currently serving in Iraq. "Because that's where we felt, in the Cold War, the emphasis had to be, for the coördination of forces on a very large scale. That didn't set us up for success when we found ourselves in Iraq. It is a very granular environment, a very block-to-block environment."

Soldiers had no consistent way to submit reports; many carried old-fashioned "green books" for handwritten notes, while some tried to set up homegrown databases. And report writing varied from camp to camp. The need for something better was obvious. In 2005, DARPA started tackling the problem at Fort Hood, TX, with the help of returning soldiers from the First Brigade Combat Team. Programmers from companies that contracted with DARPA (including Ascend Intel, where Slaughter is now director of business development) interviewed soldiers to learn what they needed.

A prototype of the system was shown to soldiers for the first time during a training exercise at Fort Hood in April 2006, and in January 2007, it was introduced in Iraq. There, programmers observed how the troops used it; they collected feedback and

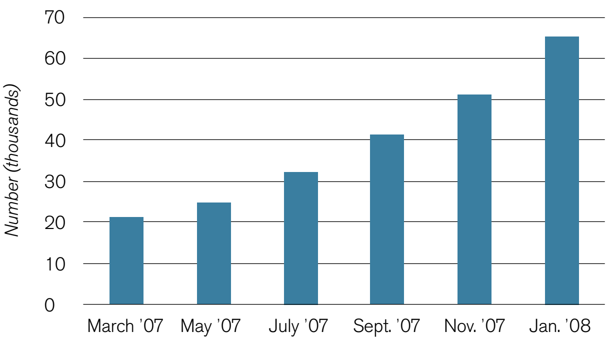
quickly made changes. Finally—with help from the Rapid Equipping Force, an army unit devoted to quickly moving new gear into the field—the system reached the 1,500 patrol leaders using it now. Deploying it widely required dealing with two main challenges raised by Iraq's spotty data connections: how to synchronize scattered copies of the same database, any one of which a returning patrol leader might modify, and how to give soldiers multimedia information without crashing the system. One solution was a network that carefully rations out bandwidth. For example, the default mode for any photograph is a thumbnail version. A soldier has to click on the thumbnail to see a larger version and will get a response only if bandwidth allows.

"This is something I've heard from a couple of generals: there are lots of technologies that get pushed out to Iraq because engineers want to help, but they are niche applications," says Mari Maeda, the DARPA program manager in charge of the effort. "This application is broadly used by patrol leaders, on a day-to-day basis. I think the impact is very, very large." O'Neal offers an even less restrained assessment: "Best technology I've seen for small units in the past 40 years."

Walter Perry, a senior researcher at the Rand think tank in Arlington, VA, and a Vietnam-era army signals officer, also welcomes the new system. Perry works with a Pentagon-wide task force that has been trying to combat the scourge of IEDs through advanced intelligence gathering and new kinds of sensors and detectors. "One of the very first things we did in looking at the IED problem was to recognize that the army is trying to fight an insurgency with a pretty blunt instrument," Perry says. "This is about 90 percent police work and 10 percent violent conflicts. Patrols—the cop on a beat—fill out a report saying, Here is what I did. You get situational awareness." And that is of key importance in fighting IEDs, he says.

IRAQ WAR DATA

Cumulative number of entries, including events (such as attacks, site visits, meetings, and discovery of weapons caches) and places (such as mosques, checkpoints, and boundaries), in the Tactical Ground Reporting System (TIGR) database available to patrol leaders.



TECHNOLOGY GAP

With the new DARPA technology, soldiers are getting more and better information. But some experts say that for the soldiers to be truly empowered, military doctrine and organization will need to change too. "I have seen one after another of these interesting networking technologies come along, and none of them has made a dent in the institutional resistance to organizational change or doctrinal innovation," says John Arquilla, a professor of defense analysis at the Naval Postgraduate School in Monterey, CA, who is a progenitor of the concept of network organization in the military. Yes, he says, patrol leaders can now enter information into the system more easily. But "we still have divisional-, brigade-, and battalion-level structures, mostly on supersized forward operating bases, with the number of smaller outposts relatively few. If we are going to talk about a networked warfare, we need to put the network front and center in our thinking." One way to do that is to deploy soldiers in smaller groups with more authority to make decisions.

That's what happened in 2001, when special-operations forces were chasing al-Qaeda and the Taliban in the mountains of Afghanistan. When a team identified a target, it did not have to send a report up the chain of command and wait for a decision before acting. It could call on comrades and even call in air strikes. "If you believe that the real implication of the Information Age is the empowerment of small groups—and if there is any lesson from 9/11, that is it—we are really talking about information that allows small groups of people to do striking things," says Arquilla. The Iraq counterinsurgency should fight the same way the special forces fought in Afghanistan, he says.

Still, even without the kinds of organizational changes that Arquilla is advocating *(see "Network Warfare," p. 12)*, DARPA's new software system is empowering frontline soldiers and shaping operations. For example, in a telephone interview from Camp Falcon, 28-year-old Captain David Lively described how TIGR once helped soldiers track down a pair of mortar attackers. One night, Lively recalled, soldiers on patrol radioed back to base that they were being shelled. At the base, other soldiers tapped into the database and quickly found earlier reports of mortars coming from an intersection of two canals in the vicinity. "TIGR provided some real-time history to where we could look back where a common source was coming from," Lively said. The soldiers at the base radioed the findings to their comrades and to a circling Apache helicopter. The pilot headed for the spot and was able to pursue a fleeing pickup truck with mortar tubes in its bed.

Michaelis says such anecdotes are not uncommon. "I can't name the number of times that patrol leaders and company commanders have turned to me and stated [that] their most important tool they have to fight this fight has been TIGR," he wrote. "I've had ... time-sensitive operations that were able to make associations between the target being handed to them and local residents, [allowing the soldiers to find insurgents who otherwise would have escaped]. I've had patrol leaders avoid potential IED hot spots or pass on IED tactics to their fellow patrol leaders."

And the technology is poised to expand. For now, it is accessible only at military bases. The next step, says Maeda, is to install it in Humvees and other military vehicles, allowing soldiers to download and act on new information in real time. Some of these vehicles already have some low-bandwidth connections, and Maeda says DARPA is working on ways to make the software work using these thin pipes. In addition, the system may soon deliver new kinds of information. In the next two to three years, it could offer surveillance pictures from circling unmanned aerial vehicles (UAVs) or other sensor systems. It could store biometric information, so that a soldier could see if a civilian being interviewed was a known insurgent suspect. "There is a whole list of enhancements that users have requested that we want to fill," Maeda says.

If those enhancements are realized, the result will look a lot like a deployed version of what the Pentagon's big R&D programs have been pursuing. But TIGR is growing organically, in response to the needs of soldiers on the ground. It might be going too far to say that this technology will be the one to force doctrinal and organizational change; perhaps not everyone will embrace it. "No doubt it causes discomfort in those comfortable in traditional intel development," Michaelis writes. As O'Neal points out, however, everyone involved in fighting the Iraq insurgency is motivated to save soldiers' lives by every means possible. In some cases, it's quite personal. "I'm focused on contemporary technology for the current force," O'Neal says. "It's all for my son." TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

By JEFFREY MACINTYRE

Microsoft's Shiny New Toy

PHOTOSYNTH IS DAZZLING, BUT WHAT IS IT FOR?

At last March's Technology, Entertainment, Design (TED) conference in Monterey, CA, a summit that's been described as "Davos for the digerati," the calm-voiced software architect from Microsoft began his demonstration abruptly, navigating rapidly across a sea of images displayed on a large screen. Using Seadragon, a technology that enables smooth, speedy exploration of large sets of text and image data, he dove effortlessly into a 300-megapixel map, zooming in to reveal a date stamp from the Library of Congress in one corner. Then he turned to an image that looked like a bar code but was actually the complete text of Charles Dickens's *Bleak House*, zooming in until two crisp-edged typeset characters filled the screen, before breezily reverse-zooming back to the giant quilt of text and images.

Microsoft had acquired Seadragon the previous year—and with it the presenter, Blaise Agüera y Arcas. But Agüera y Arcas had not come to TED just to show off Seadragon. Soon he cut to a panorama tiled together from photos of the Canadian Rockies; the mosaic shifted as he panned across it, revealing a dramatic ridgeline. Next came an aerial view of what appeared to be a model of a familiar building: Notre Dame Cathedral. The model, Agüera y Arcas explained, had been assembled from hundreds of separate images gathered from Flickr. It was a "point cloud"—a set of points in three-dimensional space.

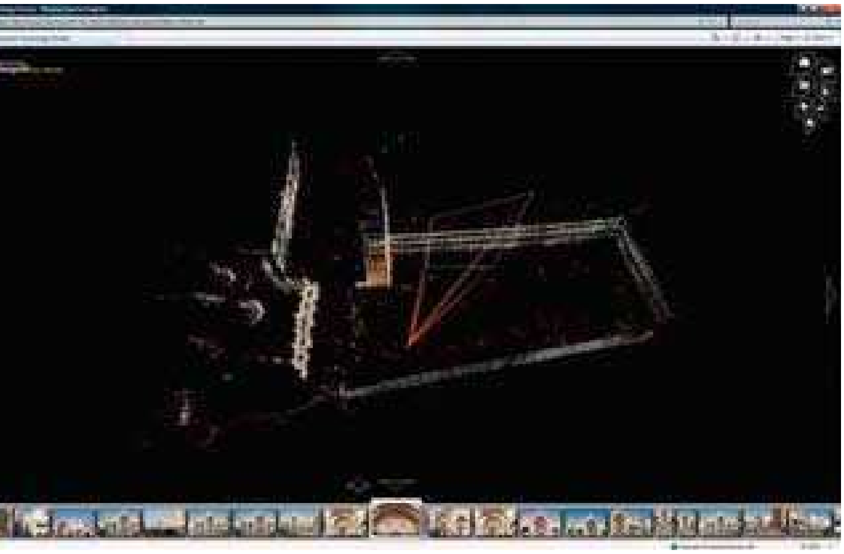
As he talked, Agüera y Arcas navigated teasingly around the periphery of Notre Dame, which repeatedly came alive and dimmed again. The effect of hurtling through shifting images and focal points was softened by subtle transitional effects. It felt like a deliberately slowed reel of frame-by-frame animation; the effect was jolting. The crowd watched in wonder as Agüera y Arcas pushed deeper into the front view of the building's archway, ending with a tight close-up of a gargoyle. Some of the images the technology had drawn on were not even strictly photographic: it had searched Flickr for all relevant images, including a poster of the cathedral. What Agüera y Arcas was demonstrating wasn't video, but neither was it merely a collection of photos, even a gargantuan one. It was also like a map, but an immersive one animated by the dream logic of blurring shapes and shifting perspectives.

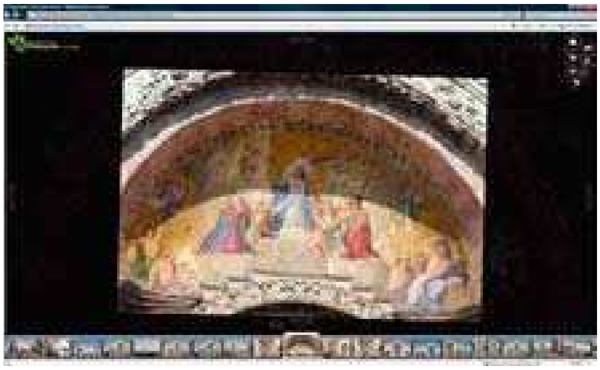
This was Photosynth—a technology that analyzes related images and links them together to re-create physical environments in a dazzling virtual space. The technology creates a "metaverse," Agüera y Arcas said (for more on the nascent blending of mapping

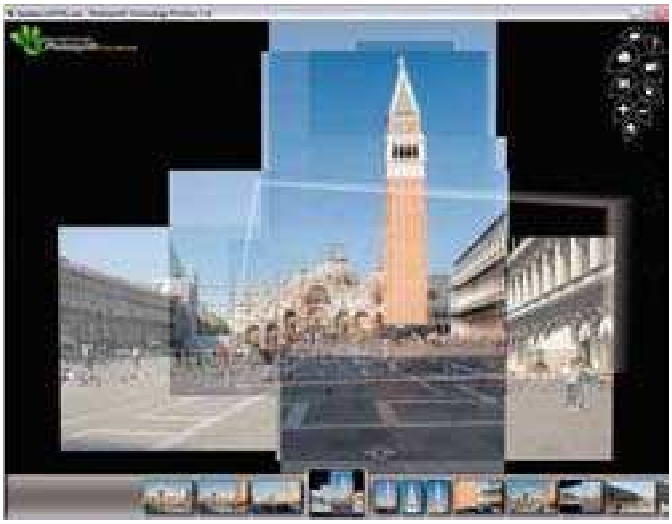
technologies like Google Earth and the fantastic realms of games like Second Life, see "Second Earth," July/August 2007); but it also constitutes the "long tail" of Virtual Earth, Microsoft's competitor to Google Earth, because of its ability to draw from and contribute to the wealth of local mapping and image data available online. It could provide "immensely rich virtual models of every interesting part of the earth," he said, "collected not just from overhead flights and from satellite images and so on, but from the collective memory." At which point the presentation ended as abruptly as it had begun some six minutes earlier. Agüera y Arcas's concluding statement met with a thunder of applause.

BEYOND IMAGE STITCHING

Photosynth was born from what Agüera y Arcas calls the marriage of Seadragon and Photo Tourism, a Microsoft project intended to revolutionize the way photo sets are packaged and displayed. Photo Tourism had begun as the doctoral thesis of a zealous 26-year-old University of Washington graduate student named Noah Snavely. One of Snavely's advisors was Rick Szeliski, a computer-vision researcher at Microsoft Research, the company's R&D arm. "I described the need for the good elements of a strong slide show, like great composition," recalls Szeliski, whose earlier work at Microsoft had helped develop the image-stitching technology now commonly used in digital cam-







YOU ARE HERE Photosynth, an application in development at Microsoft's Live Labs, offers an immersive way to view photos of a given thing or place. The software has not yet been released, but Microsoft is demonstrating it online with photo collections such as this one of Venice's St. Mark's Square. Photosynth can recognize images that share features and knit them into a larger whole. The top left image is a distant perspective on the virtual space created by Photosynth. Black predominates because much of the square has not been photographed, but zooming in reveals detailed composites like the one at left. The shots in this collection were taken by a single photographer over 10 days, but Photosynth is designed to work with pictures taken by hundreds of different people, as with images found on the photo-sharing site Flickr.

COURTESY OF MICROSOFT LIVE LABS

eras to fill a wider or taller frame. He also sought fluidity between images and a sense of interactivity in viewing them.

Working with Szeliski and a University of Washington professor named Steve Seitz, Snavely was intent on coding a way forward through a computationally forbidding challenge: how to get photos to merge, on the basis of their similarities, into a physical 3-D model that human eyes could recognize as part of an authentic, real-world landscape. Moreover, the model should be one that users could navigate and experience spatially. Existing photo-stitching software used in electronic devices such as digital cameras knew how to infer relationships between images from the sequence in which they'd been taken. But Snavely was trying to develop software capable of making such assessments in a totally different way. He devised a two-step process: "In the first step, we identify salient points in all the 2-D images," he says. "Then we try and figure out which points in different images correspond to the same point in 3-D."

"The process," Snavely says, "is called 'structure from motion.' Basically, a moving camera can infer 3-D structure. It's the same idea as when you move your head back and forth and can get a better sense of the 3-D structure of what you're looking at. Try closing one eye and moving your head from side to side: you see that different points at different distances will move differently. This is the basic idea behind structure from motion."

Computer vision, as Agüera y Arcas explains, benefits from a simple assurance: all spatial data is quantifiable. "Each point in space has only three degrees of freedom: x, y, and z," he says.

Attributes shared by certain photos, he adds, help mark them as similar: a distinctively shaped paving stone, say, may appear repeatedly. When the software recognizes resemblances—the stone in this photo also appears in that one—it knows to seek further resemblances. The process of grouping together images on the basis of

Photosynth's startling technical achievement is like pulling a rabbit from a hat: it produces a lifelike 3-D interface from the 2-D medium of photography.

matching visual elements thus gathers steam until a whole path can be re-created from those paving stones. The more images the system starts with, the more realistic the result, especially if the original pictures were taken from a variety of angles and perspectives.

That's because the second computational exercise, Snavely says, is to compare images in which shared features are depicted from different angles. "It turns out that the first process aids the second, giving us information about where the cameras must be. We're able to recover the viewpoint from which each photo was taken, and when the user selects a photo, they are taken to that viewpoint." By positing a viewpoint for each image—calculating where the camera must have been when the picture was taken—the software can mimic the way binocular vision works, producing a 3-D effect.

As Szeliski knew, however, the human eye is the most fickle of critics. So he and his two colleagues sought to do more than just piece smaller parts into a larger whole; they also worked on transition effects intended to let images meet as seamlessly as possible. The techniques they refined include dissolves, or fades, the characteristic method by which film and video editors blend images.

In a demo that showed the Trevi Fountain in Italy, Photo Tourism achieved a stilted, rudimentary version of what Photosynth would produce: a point cloud assembled from images that represent different perspectives on a single place. More impressive was the software's ability to chug through banks of images downloaded from Flickr based on descriptive tags—photos that, of course, hadn't been taken for the purpose of producing a model. The result, Szeliski remembers, was "surprising and fresh" even to his veteran's eyes.

"What we had was a new way to visualize a photo collection, an interactive slide show," Szeliski says. "I think Photo Tourism was surprising for different reasons to insiders and outsiders. The insiders were bewildered by the compelling ease of the experience." The outsiders, he says, could hardly believe it was possible at all.

And yet the Photo Tourism application had an uncertain future. Though it was a technical revelation, developed in Linux and able to run on Windows, it was still very much a prototype, and the road map for developing it further was unclear.

In the spring of 2006, as Snavely was presenting Photo Tourism at an internal Microsoft workshop, Blaise Agüera y Arcas, then a new employee, walked by and took notice. He had arrived recently thanks to the acquisition of his company, Seadragon, which developed a software application he describes as "a 3-D virtual memory manager for images." Seadragon's eye-popping appeal lay in its ability to let users load, browse, and manipulate unprecedented quantities of visual information, and its great technical achievement was its ability to do so over a network. (Photosynth's ability to work with images from Flickr and the like, however, comes from technology that originated with Photo Tourism.)

Agüera y Arcas and Snavely began talking that day. By the summer of 2006, demos were being presented. The resulting hybrid product—part Photo Tourism and part Seadragon—aggregates a large cluster of like images (whether photos or illustrations), weaving them into a 3-D visual model of their real-world subject. It even lends three-dimensionality to areas where the 2-D photos come together. Each individual image is reproduced with perfect fidelity, but in the transitions between them, Photosynth fills in the perceptual gaps that would otherwise prevent a collection of photos from feeling like part of a broader-perspective image. And besides being a visual analogue of a real-life scene, the "synthed" model is fully navigable. As Snavely explains, "The dominant mode of navigation is choosing the next photo to visit, by clicking on controls, and the system automatically moving the viewpoint in 3-D to that new location. A roving eye is a good metaphor for this." The software re-creates the photographed subject as a place to be appreciated from every documented angle.

Photosynth's startling technical achievement is like pulling a rabbit from a hat: it produces a lifelike 3-D interface from the 2-D medium of photography. "This is something out of nothing," says Alexei A. Efros, a Carnegie Mellon professor who specializes in computer vision. The secret, Efros explains, is the quantity of photographs. "As you get more and more visual data, the quantity becomes quality," he says. "And as you get amazing amounts of data, it starts to tell you things you didn't know before." Thanks to improved pattern recognition, indexing, and metadata, machines can infer three-dimensionality. Sooner than we expect, Efros says, "vision will be the primary sensor for machines, just as it is now for humans."

WHAT IT MIGHT BECOME

Microsoft's work on Photosynth exemplifies the company's strategy for the 100-person-strong Live Labs. Part Web-based skunk works, part recruiting ground for propeller-heads for whom the corporate parent is not a good fit, Live Labs aims in part to "challenge what people think Microsoft is all about," says Gary Flake, a 40-year-old technical fellow who is the lab's founder and director. Its more immediate aim is to bring Web technologies to market.

Flake's pitch about the Live Labs culture is an energetic one, as he speaks about his efforts to bridge research science and product engineering. Flake, who has worked for numerous research organizations, including the NEC Research Institute and Yahoo Research Labs, which he founded and also ran, describes this as an industry-wide challenge. At Live Labs, "we have a deliberate hedge portfolio," he explains. "We have a very interesting mix," encompassing "40 different projects."

Flake is unwilling to discuss many of his projects in detail, but he brims with excitement about his mandate to "to bring in more DNA" in the way of raw talent. "We want to create and advance the state of Internet products and services," he says, but he also speaks passionately about Live Labs employees as "human Rosetta stones" who can serve as translators in an R&D world where engineers and scientists often, in effect, speak different languages.

The Photosynth project, Flake says, epitomizes the kind of success he wants to champion through his efforts to overcome the traditional divide between science and product engineering. It "represents a serious advancement of the state of the art."

Currently, Photosynth can be seen only in an online demo, but Agüera y Arcas's team hopes to release it by the end of the year. What somebody who acquires it can actually do with it remains to be seen. Point clouds can be made from as few as two or three images, so one can imagine users creating relatively unsophisticated synths of their own photography—of, say, a family trip to Mount Rushmore. (Of course, people who have Photosynth might begin to shoot many more pictures of a given place, in the interest of being able to make a rich synth later.) But it could also be that users will tap into online libraries of photos—which will probably have to be downloaded to a local computer—to create their own synths of highly photographed sites.

Still, Photosynth is mostly promise with little proof. Technical questions abound as to how easy it will be to use and what, exactly, its capabilities will be. Also, despite the Linux origins of Photo Tourism, Photosynth will remain Windows only for the foreseeable future.

And for all Photosynth's immediate appeal, its applications, too, remain unclear. The world doesn't need another image browser, even a groundbreaking one. It seems even more unlikely that users would pay for Photosynth in its current form. In the meantime, Photosynth's fortunes will depend on whether it can build a broad-based community of users. Will it take on new uses for those who embrace it, as Google Earth has done? More important, will Microsoft release a final product sufficiently open that such a community can seek uses different from those initially intended?

WWW

Photosynth developers explain how they create panaromas: **technologyreview.com/photosynth.**

BUT WHEN WILL PHOTOSYNTH LAUNCH? Microsoft's Live Labs took thousands of pictures of the space shuttle *Endeavor* before its August 2007 mission to the International Space Station; the collection, which includes shots of the vehicle assembly building, is available on the Photosynth website.

COURTESY OF MICROSOFT LIVE LABS

Flake reports that the Photosynth team has conjured dozens of potential uses, two of which look especially likely.

One is to integrate it more fully with Microsoft Virtual Earth, making it that tool that takes users to the next step in deep zoom. With Virtual Earth handling topography and aerial photography while Photosynth coördinates a wealth of terrestrial photographic material, the two applications could give rise to a kind of lightweight metaverse, to use the term that Agüera y Arcas invoked at TED.

Noting Photosynth's facility with buildings and city squares, Seitz also envisions a "scaling up in a big way." "We'd like to capture whole cities," he says. Indeed, Agüera y Arcas and Stephen Lawler, general manager of Microsoft's Virtual Earth project, announced in August 2007 in Las Vegas, at the annual hackers' convention Defcon, that they're planning a partnership. Once some relatively minor technical hurdles are cleared, Seitz says, "there's nothing stopping us from modeling cities."

As people create and store ever greater amounts of digital media, Photosynth might even enable users to "lifecast" their family photo albums. "Imagine if you could watch your kids grow up in your own house," says Flake, "just from your photo collection."

As such ideas percolate, the Photosynth team is hardly sitting still. Last summer the researchers released an online demo collaboration with NASA, and now they are working with the Jet Propulsion Lab to synth a small part of the surface of Mars.

One does wonder how far Microsoft is willing to bankroll this kind of geek-out. Then again, as Agüera y Arcas and Flake ask rhetorically, how does one put a value on this kind of technical achievement? For while Photosynth seems somewhat lacking in a clear path to market, it also seems wholly lacking in competition. TR

JEFFREY MACINTYRE IS A FREELANCE JOURNALIST WHO WRITES WIDELY ON CULTURE, SCIENCE, AND TECHNOLOGY.

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Art Games

DIGITAL ARTISTS ARE USING GAME TECHNOLOGIES TO CREATE BOLD NEW WORKS.

By CHRISTIANE PAUL

Digital art takes many forms: installations; Internet art; virtual-reality projects that use devices such as headsets and data gloves to immerse participants in a virtual world; software coded by the artist; or even "locative media" art that uses mobile devices (such as cell phones) to turn public spaces like buildings or parks into a canvas.

Digital photographs, films, and videos have been common in the arts since the 1990s; even paintings and sculptures are now sometimes produced with the aid of digital tools. But projects that use digital technologies as a medium in themselves—and that, like their medium, are interactive, collaborative, customizable, and variable—still occupy the margins of art institutions and find their audience mostly at new-media art festivals or on the Internet.

A few artists use digital technologies as a medium for reconfiguring more traditional forms such as paintings, photographs, or videos. Among them are Brody Condon, John Gerrard, and Alex Galloway and the Radical Software Group (RSG). All use the technologies of game development to investigate the status of traditional media in the digital age. Their works consider how the digital medium has changed the nature of representation, erasing the boundaries between established categories such as painting, photography, cinema, and sculpture.

All these artists generate images that are reminiscent of paintings or photographs, yet change and evolve. Condon, Gerrard, and RSG create computer-generated 3-D scenes that are framed—in that they show a clearly delineated view, like a photograph, rather than being navigable worlds, like a game—and at the same time have a temporal, cinematic element in that they change over time. However, the cinematic movements are not simply video loops that repeat; rather, the changes are generated in real time, algorithmically. John Gerrard's projects, in particular, could be described as image-objects, artworks that are as much images as they are three-dimensional sculptures in virtual space.

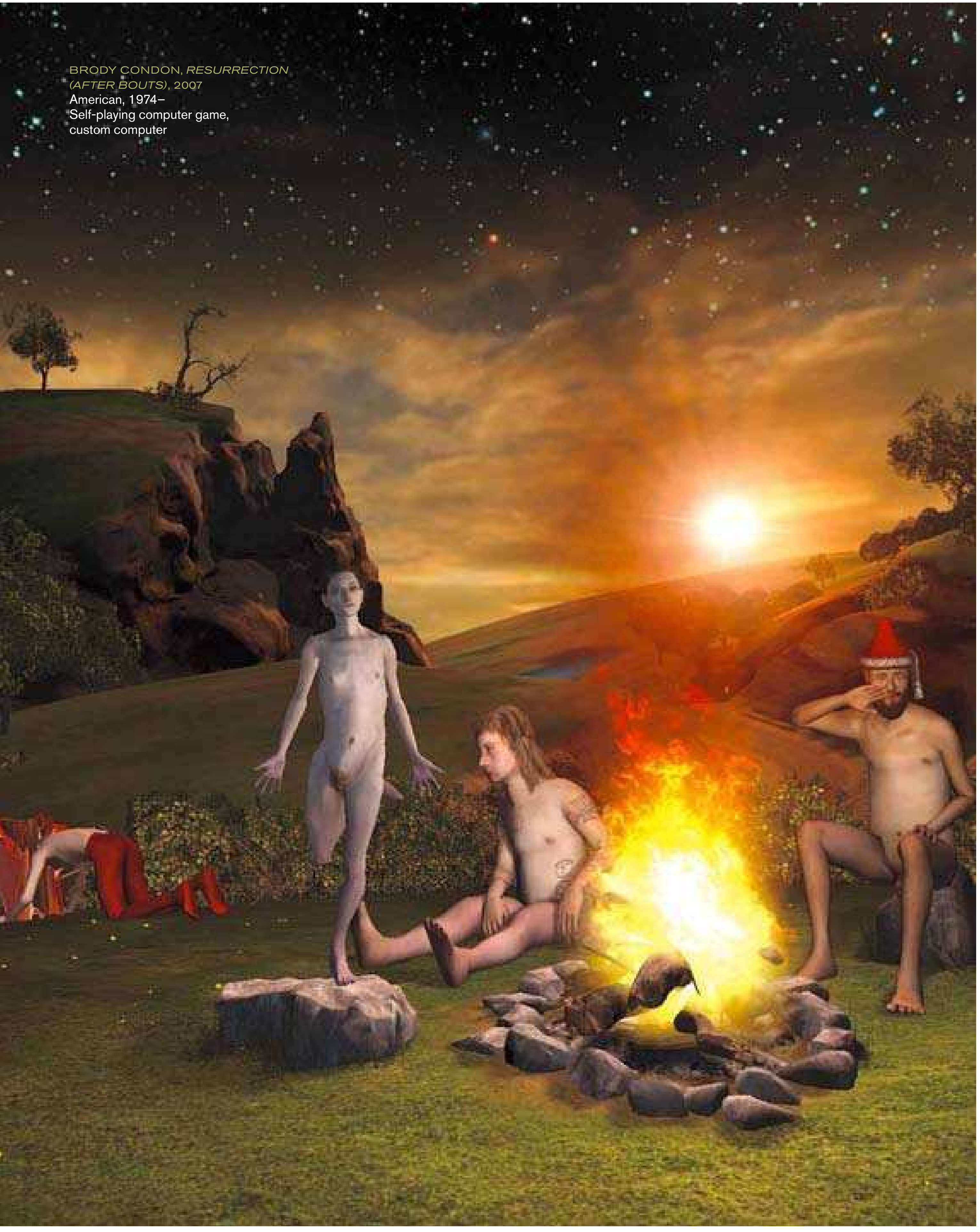
The combination of painterly, photographic, sculptural, and cinematic elements in these works would not be possible without current game-development technologies. Over the past decade, computer games have become an inspiration for artists in new media. Gaming references in digital art have been called a trend or a new style—a description that neglects many of the inherent and historical connections between computer games and new media. Early on, games explored concepts now common in digital art, such as navigation and simulation, points of view, nonlinear narrative, and the creation of 3-D worlds. Many if not most successful video games are violent "shooters" seemingly far removed from art. Yet they often create sophisticated, navigable, immersive worlds. It is only natural that digital artworks should take a critical look at computer games in a different context.

Computer games are successful, in part, because their virtual worlds can be expanded and modified. Games frequently come with "level editors" that give amateur designers the tools to develop their own virtual environments and gaming scenarios, or to customize game content by creating modifications (often called "mods") or patches—extensions that change features of the game world or the behavior of characters.

Some artists have used level editors or game engines—the core software of computer games, which runs their real-time graphics and audio, among other things—to create mods for commercial games or to generate stand-alone scenes. Others have designed their own games from scratch. But both types of gaming artwork have critically examined the politics and aesthetics of their commercial cousins. While most art based on gaming technology makes the technology itself its subject, Brody Condon's *Three Modifications,* John Gerrard's *Dust Storm (Dalhart, Texas)* and *Animated Scene (Oil Field)*, and RSG's *Prepared Playstation* more explicitly focus on the representational qualities of the 3-D image.

Condon's *Three Modifications*, which was shown at New York's Virgil de Voldère gallery in 2007, reinterprets several late-medieval Flemish (or Early Netherlandish) religious paint-

COURTESY OF BRODY CONDON



BRODY CONDON, *RESURRECTION (AFTER BOUTS)*, 2007
American, 1974–
Self-playing computer game, custom computer

DIERIC BOUTS, *RESURRECTION*, C. 1455
Flemish, c.1420–1475
Distemper on linen
89.9 x 74.3 centimeters
The Norton Simon Foundation

JOHN GERRARD,
DUST STORM (DALHART, TEXAS), 2007
Irish, 1974–
Real-time 3-D on plasma screen
Sculptural display: 78 x 87 x 31.5 inches overall, with table
Enclosed plasma screen: 44 x 68 inches
Installation shot: Marian Goodman Gallery, New York, NY

ings: panels from Hans Memling's triptych *The Last Judgement*, Dieric Bouts's *Resurrection*, and Gerard David's *Triptych of Jean de Trompes*. The landscape and overall structure of the paintings are re-created in noninteractive, animated, "self-playing" 3-D game versions that reflect on both the form and the content of the originals.

The term "Early Netherlandish" refers to a group of painters—from Van Eyck to Gerard David—working in the Netherlands in the 15th and early 16th centuries and representing a particular moment: the zenith of the Middle Ages and the transition to the Renaissance, an era when perspective—the technique artists use to mimic how three-dimensional objects appear to the eye—developed in several stages. On a formal level, Condon's work draws parallels between the evolution of perspective and realism in medieval art and the evolution of 3-D computer graphics in games. Another link between medieval art and computer games is the affection that role-playing games—from Dungeons and Dragons to Ultima Online, Everquest, and World of Warcraft—have for what Umberto Eco has called "neomedievalism." In his 1973 essay "Dreaming in the Middle Ages," Eco writes of the "avalanche of pseudo-medieval pulp" in pop culture and points out that many organizational structures of the Western world, from merchant cities to capitalist economies, have their roots in the Middle Ages. The medieval elements characteristic of many contemporary computer games where technology and magic are happily confused may express the quest for the heroic foundations of contemporary culture.

The background of Dieric Bouts's original *Resurrection* painting—a panel from one of the altarpieces for which he is famous—is a wide, serene expanse of land. Conveying an austere spirituality, Bouts's rigid composition shows Christ rising from the tomb, surrounded by an angel and three other figures in emotional states ranging from indifference to trepidation to shock. Condon re-creates the original landscape and adds a temporal element by depicting a sky caught in a state between day and night, with clouds and stars circling overhead while the sun is trapped in the moment of setting or rising. The compositional elements of Condon's game modification portray the animated image itself as caught in a specific moment—a moment that captures the parallels between the development of realistic perspective in late-medieval art and in video games, as well as the transition between the two-dimensionality of painting and the real-time three-dimensionality of computer games.

While the landscape in Condon's *Resurrection* mirrors the one in the original, the scene unfolding is substantially different: Christ is missing, his tomb has become an animated campfire, and the four surrounding figures are either nude or seminude. The angel has been replaced by a nude woman

COURTESY OF JOHN GERRARD

JOHN GERRARD, *ANIMATED SCENE (OIL FIELD)*, 2007
Irish, 1974–
Real-time 3-D, Corian display solution,
117 x 68 x 53 centimeters (two elements)

RSG, *RSG-THUG2*, 2005
Prepared PlayStation

moving in and out of a yoga tree pose; two men sit by the fire, one looking away from it, the other looking into it with a hand raised for protection, both apathetically imitating the poses in the original painting; and the figure in red tights, who in the original lies face down in front of the tomb next to a helmet, has moved to the background, where it rolls its deformed, abstracted, polygonal head from side to side. By eschewing interactivity, which is at the core of video games, and setting a boundary for the scene and the movement within it, Condon creates a different kind of space for meditation. The religious themes and iconography of the medieval painting have been transformed into those of a countercultural spirituality rooted in the 1960s. In Condon's *Resurrection*, the savior is absent, and the other characters are thrown back on themselves. The fact that the work exists in a virtual world and a game environment points to a contemporary way of transcending the body: the avatar as a virtual alter ego. In his *Resurrection*, Condon contrasts and plays with cultural iconography and archetypes (or even stereotypes) of different centuries, using the parallels between medievalism and gaming environments.

Condon creates his modifications by means of the Unreal Runtime Engine, a stripped-down version of the game engine for the first-person-shooter game Unreal Tournament 2003. Within the scenes, the point of view that would normally move around the space remains still. Condon places the 3-D visual content he developed in the game space and then moves the camera through the space to reproduce the composition of the original painting. Characters and landscape are tilted forward 45°, toward the viewer, and stacked in order to imitate the perspectival system used by the Flemish masters.

A different take on the relationship between game-development technology and traditional media is presented in the works of John Gerrard, who has created multiple scenes of portraits and landscapes that take the form of 3-D image-objects. At first glance, his projects *Dust Storm (Dalhart, Texas)* and *Animated Scene (Oil Field)* seem to reflect photographic conventions of landscape representation. But while they allude to the medium of photography, they also undermine the "freezing" of a moment in time.

In *Dust Storm (Dalhart, Texas)*, one of a series of pieces, Ger-

WWW See digital artwork in action: **technologyreview.com/digitalart.**

rard remakes a dust storm that occurred on "Black Sunday," April 14, 1935, and depicts it as permanently looming over a representation of Dalhart, TX, in its current state. The view is based on photographs taken by the artist on site, while the image of the storm itself is derived from 1930s archival photos of the Dust Bowl. Past and present collapse in a photorealistic yet unfixed temporal image space that appears simultaneously hyperreal and fantastic. Gerrard thinks of the work as "a 'memorial structure,' a type of public art placed on the (constructed) landscape as it stands now." The storm is a custom-built particle system on which the artist and his collaborators worked for six months; once it starts, it changes over time without shifting position over the landscape. The movement of the rolling and surging cloud was created on the basis of a video of a dust storm in Iraq's Anbar Province that Gerrard had seen.

While the scene captures a single, quasi-photographic moment, the light conditions of the work cover a whole year: the orbit of the sun has been programmed so that the light of the scene accurately cycles through day and night as they vary throughout the four seasons. The temporality of *Dust Storm (Dalhart, Texas)* is therefore realistic in terms of our conventions of measuring time, in seconds, minutes, and hours. It also unfolds in real time in machine terms, since the dust storm and the light conditions are based on continuously calculated data. The events in the scene—changing light and rolling dust cloud—occur as the machine processes them. As in other works, Gerrard subtly references the effect of environmental pollution. The storms in the Dust Bowl were a result of a recurring drought combined with the effects of poor agricultural practices and industrialization.

In another landscape portrait, the diptych *Animated Scene (Oil Field)*, Gerrard networks two images of oil pumps so that they perform identical and simultaneous movements on two screens. Each image features a single, central pump flanked by two more pumps in the distance. All the pumps face east, toward the sun, and run endlessly and identically.

Gerrard's works fuse media on yet another level, since they also have a strong sculptural component: the framed screen that holds the images can be turned on a central pivot point, so the viewer can look around and behind the depicted subject in a 360° pan. Through the use of gaming technology, Gerrard makes his landscapes "navigable" in real time, while still maintaining the framing of the scene. And Gerrard's works, like Condon's, include cinematic elements as well. The movements of characters, objects, and natural elements maintain a subtle balance between stillness and motion. Gerrard refers to the image world he creates as a "postcinematic slipping space between the image and the object."

While John Gerrard and Brody Condon explore painting and photography, RSG playfully deconstructs the video loop. RSG's series *Prepared Playstation* takes its name from a series of works by John Cage, the artist and musician who wrote compositions for "prepared piano"—one whose sound had been changed by objects placed on the hammers or dampers or between strings. The "preparation" in this case is distinctly low-tech, a rubber band wrapped around the game controller so that it holds the buttons in place and makes a scene from a game play perpetually. *RSG-THUG2* (2005), a work in the *Prepared Playstation* series created for the 2005 exhibition *Logical Conclusions: 40 Years of Rule-Based Art* at the Pace Wildenstein gallery in New York, uses three scenes prepared inside the skateboarding game Tony Hawk's Underground 2. The project exploits glitches in the game's code: navigating through the game, RSG discovered moments where movement cannot be properly rendered or characters get trapped in loops. In one of the scenes from *RSG-THUG2*, the game character is skateboarding along a railing, and the game architecture "breaks open"—the image cracks and starts oscillating between the accurate representation of the image and colorful abstract forms. In all the *Prepared Playstation* scenes, RSG "catches" a particular game sequence and makes it play itself in a continuous loop. While the project references and plays with the concept of the video loop, it also reveals the architecture of its image construction, exposing the moment where the data creating the image is improperly processed.

RSG, *PREPARED PLAYSTATION*, 2005
Prepared controller

Prepared Playstation, *Three Modifications*, and John Gerrard's works all exist in a "slipping space" that opens up a new perspective on the qualities of the digital image. *Prepared Playstation* appears to be a video loop but reveals and deconstructs the creation of its images. *Dust Storm (Dalhart, Texas)*, *Animated Scene (Oil Field)*, and *Resurrection (after Bouts)* evoke painting and photography yet present scenes that are in constant motion or evolve over time and can be navigated. All the projects capture characteristics of traditional art forms and demonstrate how the digital image transcends and reconfigures them. They are 3-D image spaces that operate in real time and perpetually play themselves, suggesting a state of being driven by algorithmic calculations. TR

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REVIEWS

WIRELESS

Android Calling

DOES GOOGLE WANT TO FREE YOUR PHONE—OR OWN IT?

By SIMSON GARFINKEL

Last November, Google and 33 other companies announced the Open Handset Alliance (OHA), a new industry consortium that, in promoting open standards for mobile devices, promises to reinvent the cell phone—and possibly the entire wireless-telecommunications industry. While that's a tall order, I suspect that handsets, which Google intends to make as customizable as laptop computers, are just the beginning of the company's mobile efforts.

The word "open" in OHA's name is not just a buzzword: it signifies a radical departure from today's cellular networks, especially those in the United States. Today's cellular ecologies aren't exactly closed; it's possible to load third-party applications onto some cell phones, and websites belonging to third-party providers such as Google can be accessed. Verizon (not an OHA member) has even announced its willingness to open its network to non-Verizon phones. But that openness is all at the periphery: wireless providers today offer just enough choice in phones, features, and services to remain competitive while preventing consumers from using rival technology and defecting to other carriers.

Indeed, companies like Verizon and AT&T (also not an OHA member) operate vertically integrated telecommunication ecologies of stores, resellers, content providers, and network services—all with the goal of extracting as much revenue as possible from a customer base that's kept captive with multiuser contracts, exclusive hardware offerings, and free in-network calling. The wireless industry's favorite metric is "average revenue per user."

ANDROID SOFTWARE DEVELOPER KIT VERSION M3-RC37A
Cost: Free

This approach—using integrated services to extract maximum revenue—will slowly evaporate if OHA is successful. And the key to that success will be Android, a new software "stack" for mobile phones that's based on open-source software and a revolutionary programming paradigm.

Android is called a "stack" because its software extends from the lowest levels controlling the phone's hardware to the highest levels of user interaction. At the bottom is a stripped-down version of the Linux kernel (the heart of the Linux operating system). On top of the kernel is the open-source WebKit Web browser (also used by Apple's iPhone) and several other open-source programs. On top of this are user applications that are beautiful but, at least in the developer's preview version, primitive and buggy. Once Google finishes this release, Android is going to look as pretty as the iPhone—and it will be just as functional, if not more so.

The first thing to point out is that you can't run Android on a phone that you might have today. Instead, manufacturers like HTC, LG, Samsung, and Motorola (all OHA members) will need to adapt it to future handsets. If the consortium has its way, these phones will be available in stores in the second half of 2008. You'll also be able to buy an Android-based phone over the Internet and drop in a chip from the cell phone that's in your pocket today, assuming you have a cell phone from T-Mobile, AT&T, or another provider that uses the GSM transmission standard.

Android's developers envision a world where today's integrated wireless systems are reduced to a set of relationships between parts that are more or less interchangeable. Consumers will be free to load their phones with applications of their own choosing—free applications, applications available for sale, and custom applications developed by enterprises for their employees. These applications will be able to communicate with third-party services offered over the Internet—using any available communications pipe, be it the cellular network, a nearby Wi-Fi connection, or even a Bluetooth connection from another phone.

The key to realizing this vision is a set of clean, documented, standardized interfaces that allow each part of the handset environment to interact with every other. For example, Android includes a so-called location provider interface. Services that might want to know where your handset is—such as Google Maps, navigation applica-

TAVIS COBURN

tions, or even special-purpose applications that show you advertisements or offer you coupons based on your location—can use the interface to access technologies that can figure out where you are. These might include a GPS receiver built into your phone or a location service offered by your wireless provider.

This feature is good news for companies whose business model is based on providing information to consumers—and possibly showing them advertisements. It's terrible news for those whose business model is based on charging consumers to access hardware built into their own devices—the way Verizon does with its VZ Navigator, a navigation service that uses the GPS receiver standard in new Verizon phones and costs $9.99 a month or $2.99 a day.

AN ARCHITECTURE FOR MASHUPS

Does Android have what it takes to blow apart the silos in today's cellular-telephone marketplace and open it to the chaos of competition? Although the developer's preview is flawed, Android's architectural choices and development tools show great promise.

What's more, though Android itself is brand new, it draws from proven Google software. Consider Google Maps, which has been one of Google's most successful offerings to date. With little effort, practically any Web developer can create a "mashup" that drops geographical annotations like photos, routes, and notes about particular places onto a beautiful, interactive, and highly functional map *(see "Second Earth," July/August 2007)*. Android might, because of the way it is built, be able to replicate the versatility of Google Maps with respect to the phone itself. Unlike conventional mobile operating systems, which see each application as an essentially monolithic whole, Android splits a given app into multiple parts, with well-defined interfaces between them. This makes it easy for developers to write component-based applications.

Interestingly, Android's component-based structure could also extend battery life. On a system like Windows Mobile, programs spend a lot of time running in the background, where they use memory and drain the battery. With Android, only a tiny piece of each application should need to run at any time; the other parts could shut down. As a result, it should feel more responsive yet use less power.

Developing for cell phones is normally much harder than developing for desktops: because far fewer developers work with cell phones than with desktop applications, the tools are less polished and harder to use. With Android, Google has rewritten the rules here as well. Developers write Android applications in the ubiquitous Java programming language, so there are already millions of would-be Android programmers. The free Android developer kit includes a telephone emulator, which lets any developer with a PC, Mac, or Linux desktop write and test Android applications. The emulator even makes it possible to control the speed and quality of the simulated phone's network connection, allowing developers to see how their programs will behave on phones in poor coverage areas without having to load the applications onto real phones.

WHAT'S NEXT

Android is not the "Google phone" that rumor suggested before the software was launched. Indeed, the company doesn't really want to own your phone. It just wants to be sure that no other company does. If Android succeeds, it will keep the wireless world safe for Google and whatever services it might seek to offer in the future. Today there are a billion Internet

users but nearly three billion people with mobile phones. That's a lot of eyeballs, and Google is first and foremost an advertising firm. And so it is not surprising that Google may do more than build a new operating system in its effort to entrench itself in the wireless world. At press time, the company was in the process of bidding for wireless-spectrum licenses being auctioned by the Federal Communications Commission.

If Android succeeds, it will have a major impact on wireless carriers. A phone running Google's component-based operating system, after all, would treat wireless operators like Verizon and AT&T as just another way to reach data services on the Internet. Such a phone could turn today's wireless providers into commodity data communications networks that also happen to carry voice. This would force the providers to compete in every area—network quality, handset quality, and price—without allowing good performance in one area to lock customers in and support mediocre performance in another. T-Mobile (an OHA member) already gets it: some of its newest phones allow calls over either T-Mobile's GSM network or Wi-Fi. I think this change will happen even without the Google phone. I'm seeing more unlocked phones with Wi-Fi capability from companies like Nokia (not an OHA member); just drop in an AT&T SIM card and they'll play on AT&T's network. But though the change may happen anyway, Google is pushing it along at a faster clip.

Just as Google's place in the wireless world is a work in progress, so too is Android, which I suspect will not be limited to cell phones. If it's successful, we're likely to see Android as the basis of other handheld devices: digital cameras, GPS receivers, or even lightweight tablet computers. If Android really works, it's going to change the face of mobile computing. TR

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LEGISLATION

The Mess of Mandated Markets

NEW FEDERAL BIOFUEL STANDARDS WILL DISTORT THE DEVELOPMENT OF INNOVATIVE ENERGY TECHNOLOGIES.

By DAVID ROTMAN

Few things prompt Washington policymakers to forget their professed belief in the efficiency of free markets faster than $100-a-barrel oil prices—or even the threat of them. In one of the most notable recent examples, as the price of crude oil edged toward the $100 mark late last year, the U.S. Congress passed, and President Bush quickly signed, the Energy Independence and Security Act of 2007.

Among its various provisions, the energy bill prescribes a minimum amount of biofuel that gasoline suppliers must use in their products each year through 2022. The new mandates, which significantly expand the Renewable Fuels Standard of 2005, would more than double the 2007 market for corn-derived ethanol, to 15 billion gallons, by 2015. At the same time, the bill ensures the creation of a new market for cellulosic biofuels made from such sources as prairie grass, wood chips, and agricultural waste. The standards call for the production of 500 million gallons of cellulosic biofuel by 2012, one billion gallons by 2013, and 16 billion gallons by 2022.

$100 CRUDE OIL
ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

Not surprisingly, the ethanol industry is very happy. The Biotechnology Industry Organization, a Washington-based trade association whose members include both large manufacturers and startup companies developing new cellulosic technologies, suggests that "this moment in the history of transportation fuels development can be compared to the transition from whale oil to kerosene to light American homes in the 1850s." The new push for biofuels, the trade association continues, is "larger than the Apollo project or the Manhattan project" and will require the construction of 300 biofuel plants, each with a capacity of 100 million gallons, at a cost of up to $100 billion.

In short, the federal government has legislated the growth of a sizable industry. The often stated aim of the biofuel standards is to reduce greenhouse-gas emissions and dependence on foreign oil. And biofuels, particularly cellulosic ones, could arguably play a significant role in achieving both those goals *(see "The Price of Biofuels," January/February 2008)*. But quite apart from the value of ethanol and other biofuels, the creation of markets by federal law raises fundamental questions about the best way to implement a national energy policy. Can legislated markets survive economic conditions and policy priorities that change over the long term? And what role should the government play in promoting specific technologies?

Mandated consumption levels break the "one-to-one link" between market demand and the adoption of a technology, says Harry de Gorter, an associate professor of applied economics and management at Cornell University: "As an economist, I don't like it. Economists like to let the markets determine what [technology] has the best chances." The new biofuel mandates are "betting on a particular technology," he says. "It is almost impossible to predict the best technology. It is almost inevitable that [mandates] will generate inefficiencies." While de Gorter acknowledges that some economists might justify mandated markets as a way to promote a desired social policy, he questions the strategy's effectiveness. "Historically, there are no good examples of it working in alternative energy," he says.

BIOFUEL BONANZA President Bush signed energy legislation in December that, among its various provisions, sets mandated consumption levels for corn ethanol and other biofuels through 2022.

CHARLES DHARAPAK/ASSOCIATED PRESS

One reason economists tend to be wary of mandated consumption levels is that they can have unintended consequences for related markets. Producing 15 billion gallons of conventional ethanol will require farmers to grow far more corn than they now do. And even with the increased harvest, biofuel production will consume around 45 percent of the U.S. corn crop, compared with 22 percent in 2007. The effects on the agricultural sector will be various and complex.

Perhaps most obvious will be the impact on the price of corn—and, indirectly, of food in general. Since it became apparent that the biofuel standards would become law, the price of corn has risen 20 percent, to around $5.00 a bushel, says Bruce Babcock, director of the Center for Agricultural and Rural Development at Iowa State University. He expects that prices will probably stay around that level for at least the next three years. Because corn is the primary feed for livestock in this country, that means higher prices for everything from beef to milk and eggs. (Less than 2 percent of the nation's corn crop is eaten directly by humans; more than 50 percent feeds animals.) High corn prices could also make it harder to switch to cellulosic biofuels, because farmers will be reluctant to grow alternative crops. With the price of corn so high, says Babcock, "who is going to replace corn with prairie grass?"

At Purdue University, Wallace Tyner, a professor of agricultural economics, has calculated how different types of government policies, including the new mandated consumption levels, will affect the economics of corn ethanol. One of his most striking findings (though one that would surprise few agricultural experts) is that the fuel struggles to compete with oil on cost, in part because of extreme sensitivity to the commodity price of corn.

Because ethanol is generally blended with gasoline at a concentration of 10 percent, its market value is directly tied to the price of oil. But Tyner's analysis illustrates the complexity of the interplay between the markets for oil, corn, and ethanol. In the absence of government subsidies or mandates, according to his model, no ethanol is produced until oil reaches $60 a barrel. But with oil at that price, ethanol is profitable only as long as corn stays around $2.00 a bushel, which limits production of the biofuel to around a half-billion gallons a year. As oil prices increase, so does ethanol production. But production levels continue to be limited by the price of corn, which rises along with both the demand for ethanol and the price of oil (farmers use a lot of gasoline). Even when oil reaches $100 a barrel, ethanol production will reach only about 10 billion gallons a year if there are no subsidies; and even then, ethanol is profitable only if corn prices stay below $4.15 a bushel. If oil hits $120 a barrel, ethanol production will, left to market forces, reach 12.7 billion gallons—still more than two billion short of the federal mandate.

In other words, the federally mandated consumption levels mean ethanol will not, for the foreseeable future, be truly cost-competitive with gasoline. Indeed, says Tyner, setting the ethanol market at 15 billion gallons will mean an "implicit tax" on gasoline consumers, who will have to pay to sustain the high level of biofuel production. When oil costs $100 a barrel, the consumer will pay a relatively innocuous "tax" of 42 cents per gallon of ethanol used (the additional price at the pump will usually be only a few pennies for blends that are 10 percent ethanol). But at lower oil prices, the additional cost of ethanol will be far more noticeable. If oil falls to $40 a barrel, the implicit tax for ethanol will be $1.05 a gallon—or $15.77 billion for all the nation's gasoline users. "If the price of oil drops substantially, is Congress going to say, 'We didn't really mean it'?" asks Tyner. "It gets really messy."

History provides a lesson about the messiness of predicting the market for an energy technology. Almost three decades ago, as the price of oil reached $40 a barrel and many experts worried that it was headed for $80 or even $100, President Jimmy Carter signed the Energy Security Act of 1980. As is the case today, the high price of oil was straining the U.S. economy, and the Middle East was unstable. One key provision of the 1980 legislation created the U.S. Synthetic Fuels Corporation, which was meant to establish a domestic industry that produced liquid fuel from tar sands, shale, and coal. Despite the unknowns surrounding the economics of producing synthetic fuels on a large scale, engineers estimated that they could be produced for $60 a barrel. An initial production target was set at 500,000 barrels a day. But in the early 1980s, the price of oil fell to $20 a barrel. With no prospect of producing synthetic fuels at a price competitive with that of oil, the Synthetic Fuels Corporation was finally shuttered in 1986.

The corporation "didn't fail because of the technology," says John Deutch, who was undersecretary of energy in 1980 and is now an Institute Professor of chemistry at MIT. Rather, he says, it failed because "it focused on production goals, and that turned out to be a bad thing because the market prices went down." Deutch believes that instead of target-

ing specific production levels, government should participate in the development of alternative fuel technologies by helping to assess their economics and determine whether they meet environmental expectations.

The Synthetic Fuels Corporation and today's Renewable Fuels Standard differ in many ways. But the efforts behind them do reflect a common theme: the federal government's attempt to select a particular technology and create a market for it. The "harsh reality" is that such measures "are unlikely to be effective over the long term," Deutch says. "And nowhere is this more obvious than in ethanol." He and other experts, such as de Gorter and Iowa State's Babcock, would prefer to see technology-neutral policies, such as a carbon or greenhouse-gas tax, that would allow the markets to choose the most cost-effective way of meeting political and environmental goals.

Besides creating the synthetic-fuels program, the 1980 energy bill also included a Biomass Energy and Alcohol Fuels Act, which provided $600 million to the Departments of Energy and Agriculture for research into biofuels made from cellulose or biomass. But that funding was slashed in subsequent years. And while the Energy Department is again aggressively funding research on biofuels, and the 2007 energy bill includes several measures supporting such work, overall federal funding for energy research and development has never fully rebounded from the cuts made during President Reagan's administration. It's one reason that, almost three decades after Jimmy Carter's energy bill, the United States still has no effective answer to high-priced imported oil.

Distorting the markets through federal mandates for biofuels won't help. What might: a well-considered federal policy that financially supports the development of promising new energy technologies and offers technology-neutral incentives for replacing petroleum. TR

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INFORMATION TECHNOLOGY

The Digital Utility

NICHOLAS CARR, WHO ARGUED THAT INFORMATION TECHNOLOGY DOESN'T MATTER, WEIGHS THE IMPLICATIONS OF CLOUD COMPUTING.

By MARK WILLIAMS

In the end, as the story of the emperor's new clothes reminds us, somebody has to break the spell. In May 2003, Nicholas Carr cast himself in the naysayer's role by publishing an article titled "IT Doesn't Matter" in the *Harvard Business Review*. In 2004 he followed that with a book, *Does IT Matter? Information Technology and the Corrosion of Competitive Advantage*. Thereby, he aroused the ire of the good and the great in Silicon Valley and Redmond, WA.

For that, he won a little fame. Now he has a new book, *The Big Switch: Rewiring the World, from Edison to Google*, which will almost certainly influence a large audience. Carr persuasively argues that we're moving from the era of the personal computer to an age of utility computing—by which he means the expansion of grid computing, the distribution of computing and storage over the Internet, until it accounts for the bulk of what the human race does digitally. And he nicely marshals his historical analogies, detailing how electricity delivered over a grid supplanted the various power sources used during most of the 19th century. Many readers may find his conclusions unconvincingly dark. I think he could have borne in mind the old joke: predicting is hard, especially about the future. That said, I also suspect he's right to suggest that in a decade or so, many things we now believe permanent will have disappeared.

THE BIG SWITCH: REWIRING THE WORLD, FROM EDISON TO GOOGLE
Nicholas Carr
W. W. Norton, 2008, $25.95

Given that Carr's conclusions are controversial, it's helpful to trace his thesis in full. In "IT Doesn't Matter," he argued that as industries mature, the products or services they supply become commodities that compete on price alone. The information technology industry, he continued, had arrived at that phase: for most companies that did not themselves develop and sell IT, information technology offered no competitive advantage and was just another cost of doing business. It wasn't hard to find evidence for Carr's contention. A business school truism since Clayton Christensen's 1997 book *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* is that you can tell a sector has been commodified when competition has created a "performance oversupply," where almost any product differentiation is unwanted. And indeed, by sometime before the 20th century's end, the vast majority of PCs had far more processing and storage capacity than their users needed for the most common tasks: e-mail, Web browsing, word processing. In fact, Carr pointed out, 70 percent of a typical Windows network's storage capacity went unused.

By 2000, Carr claimed, close to 50 percent of American companies' annual capital expenditures went to IT: every year, U.S. businesses acquired more than 100 million new PCs. The biggest IT-associated business risk that companies faced, he concluded, was overspending. It was time for businesses to "explore cheaper solutions, including open-source applications and bare-bones network PCs," he argued. "If a company needs evidence of the kind of money that might be saved, it need only look at Microsoft's profit margin."

Naturally, the industry's chieftains poured scorn on this thesis. Microsoft's CEO, Steve Ballmer, blustered that there was still plenty of life in l'ancien régime:

"Our fundamental response is: hogwash. We look out there like kids in a candy store saying what a great world we live in." Even Ethernet coinventor Bob Metcalfe, who might have maintained an Olympian detachment, weighed in to complain in this magazine that "Carr's article just won't stay debunked" *(see "Why IT Matters," June 2004)*. As evidence of Carr's wrongheadedness, Metcalfe cited the expansion of the Ethernet into ever newer, wider, and faster networking realms, thus arguably missing Carr's point. [Metcalfe is a member of *Technology Review*'s board of directors.]

Carr was saying that, like previous technologies such as the telephone and electricity, IT no longer conferred any competitive advantage because it was now part of the general business infrastructure. Next, IT would become a simple utility, provided to users over the networks that Metcalfe had helped make possible. Today, of course, Carr's thesis is the accepted wisdom: almost everybody agrees that IT services will eventually be delivered on a subscription basis, as a utility. As *The Big Switch* observes, this is why Google has been constructing gigantic server farms in rural sites in Oregon, the Carolinas, Oklahoma, Georgia, and Iowa. Elsewhere, similar data centers have been or are being built by Microsoft, IBM, Hewlett-Packard, Yahoo, Ask.com, and Salesforce.com.

The retail giant Amazon has offered the most comprehensive utility-computing services thus far. It had already introduced its EC2 (Elastic Compute Cloud, where customers run software on Amazon's systems) and S3 (Simple Storage Service, where customers store data for a few cents per gigabyte) when it recently launched SimpleDB, a website that provides metered database capabilities.

I asked Werner Vogels, Amazon's chief technical officer, whether we were truly in the era of the serverless Internet company that could be run through a browser. Vogels said that he took that as settled, given how many startups were happier paying cents per gigabyte to Amazon than investing in hardware costing hundreds of thousands of dollars.

In *The Big Switch*, Carr notes the prospective benefits of a world of utility computing, but he also plays the naysayer again. Nearly half the book describes the possible dystopian aspects of such a world. What are these, in his view?

First, the destruction of traditional businesses by the extremely lean companies that utility computing makes possible. Second, the ease with which governments and corporations will be able to track and exploit our digital behavior. Third, the emergence of a "YouTube economy" in which many will provide free information to the "cloud," and a few aggregators will harvest most of the profits. Fourth, the deterioration of human culture as people come to rely on the Internet to know and do everything, while they know and do little themselves. Fifth, the continuing fracturing of civil society as people choose to read or hear only the news that confirms their prejudices.

PHOTO: JOHN TODD/SUN MICROSYSTEMS/GETTY IMAGES

Carr's predictions vary in plausibility. Overall, though, they can be separated into two categories: on the one hand, futuristic scenarios that may or may not tip over into reality; on the other, scenarios that amount to what the great political economist Peter Drucker called "the future that has already happened." Drucker, who died in 2005, used to maintain that while trying to predict the future was pointless, it was possible to identify ongoing trends that would have significant future effects.

Drucker described his modus operandi thus: "I look out the window at things that are going on, things that have already happened that people pay no attention to." That methodology led Drucker to the conclusion that the Knowledge Economy was succeeding the Industrial, with the obvious collateral being the rise of the knowledge worker, a term Drucker was the first to use. When Nicholas Carr wrote "IT Doesn't Matter," he was doing Drucker's kind of analysis, looking out the window and identifying a future that had already happened.

In his latest book, Carr has extrapolated similarly from ongoing trends. At many small to midsize companies, not a few executives will be thinking, "We could reduce the IT department to one or two people." IT is a cost center, after all, not so dissimilar from janitorial and cafeteria services, both of which have long been outsourced at most enterprises. Security concerns won't necessarily prevent companies from wholesale outsourcing of data services: businesses have long outsourced payroll and customer data to trusted providers. Much will depend on the specific company, of course, but it's unlikely that smaller enterprises will resist the economic logic of utility computing. Bigger corporations will simply take longer to make the shift.

Though some IT managers will retrain and find work in the new data centers, such places will offer fewer jobs than they displace: for instance, informed accounts place the number of employees at Google's flagship data center in Oregon at only around 200. Similarly, entrepreneurially inclined IT managers may join startups developing innovative technologies. Again, though, the opportunities will be limited: most aspiring entrepreneurs fail. It's hard to avoid the conclusion that many IT managers—the emblematic category of knowledge worker, long assumed to be safe from the technologically fueled economic disruptions that have eliminated so many jobs—will probably lose their livelihoods. TR

MARK WILLIAMS, A CONTRIBUTING EDITOR FOR *TECHNOLOGY REVIEW*, LIVES IN OAKLAND, CA.

HACK

Amazon Kindle

THE ONLINE GIANT HOPES IT'S CREATED THE IPOD OF DIGITAL BOOKS.

By DANIEL TURNER

AMAZON'S PORTABLE, handheld reader, which allows users to download digital versions of books, newspapers, and magazines, represents one of the first consumer uses of a low-power, easy-to-read electrophoretic display. The $399 device is a breeze to use, and though the company has not disclosed sales numbers, demand quickly outstripped supply. However, the success of the Kindle may depend on consumers' willingness to bear the price of using it: though e-books, at $9.99, cost less than most physical books, newspapers, blogs, and other content available free on the Internet will cost money (for instance, $1.99 per month for Slashdot and $13.99 per month for the *New York Times*).

A | ELECTRONIC PAPER

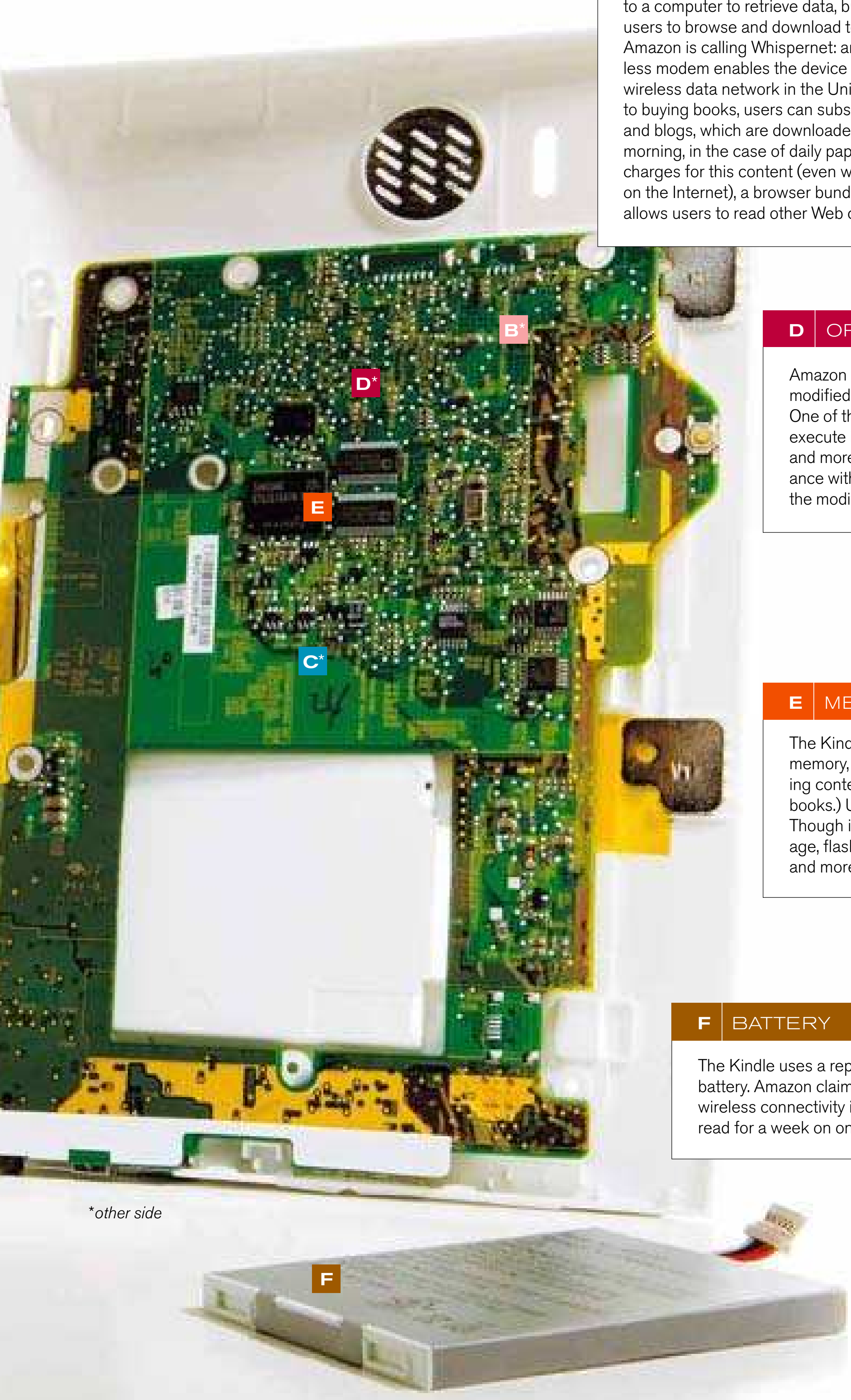
The Kindle's 600-by-800-pixel, 167-pixels-per-inch screen uses a display technology made by E Ink of Cambridge, MA. At the front of the screen is a layer of transparent electrodes. Below it are millions of microcapsules containing positively charged white particles and negatively charged black particles, and below them is a layer of nearly a million more electrodes. A negative charge on one of these bottom electrodes pushes black particles to the top, and a positive charge does the same with the white ones. Each microcapsule acts as a pixel that can thus be made to appear black, white, or gray.

E-paper consumes far less power than LCD displays do. Because the microcapsules retain their configurations until a new charge is applied, the display doesn't have to draw current until it's time to switch pages.

B | CPU

Powering the Kindle is an Intel PXA255 processor, says John Knuth, lead technician at Rapid Repair and one of the first to take apart the Kindle. This processor is part of Intel's XScale line, designed for use in mobile phones and smart phones.

WWW | Watch a video of the Kindle Hack: **technologyreview.com/hack.**



*other side

CHRISTOPHER HARTING

C WIRELESS DOWNLOADS

Most electronic readers require physical connection to a computer to retrieve data, but the Kindle allows users to browse and download texts wirelessly via what Amazon is calling Whispernet: an AnyData EVDO wireless modem enables the device to connect to Sprint's wireless data network in the United States. In addition to buying books, users can subscribe to newspapers and blogs, which are downloaded automatically—each morning, in the case of daily papers. Though Amazon charges for this content (even when it's available free on the Internet), a browser bundled with the Kindle allows users to read other Web content at no cost.

D OPERATING SYSTEM

Amazon decided that the Kindle would run a modified version of the Linux 2.6.10 kernel. One of the modifications added support for execute in place (XIP), which allows faster and more efficient memory usage. In compliance with Linux licensing, Amazon has made the modified source code freely available.

E MEMORY

The Kindle comes with 256 megabytes of internal flash memory, 180 megabytes of which is available for storing content. (On average, that's enough for about 200 books.) Users can also use SD cards for more storage. Though it's more expensive than hard-drive-based storage, flash memory offers quicker access, lighter weight, and more resistance to bumps and shocks.

F BATTERY

The Kindle uses a replaceable lithium-polymer battery. Amazon claims that when the device's wireless connectivity is switched off, users can read for a week on one battery charge.

DEMO

Ethanol from Garbage and Old Tires

A VERSATILE NEW PROCESS FOR MAKING BIOFUELS COULD SLASH THEIR COST.

By KEVIN BULLIS

As he leads a tour of the labs at Coskata, a startup based in Warrenville, IL, Richard Tobey, the company's vice president of research and development, pauses in front of a pair of clear plastic tubes packed with bundles of white fibers. The tubes are the core of a bioreactor, which is itself the heart of a new technology that Coskata claims can make ethanol out of wood chips, household garbage, grass, and old tires—indeed, just about any organic material. The bioreactor, Tobey explains, allows the company to combine thermochemical and biological approaches to synthesizing ethanol. Taking advantage of both, he says, makes Coskata's process cheaper and more versatile than either the technologies widely used today to make ethanol from corn or the experimental processes designed to work with sources other than corn.

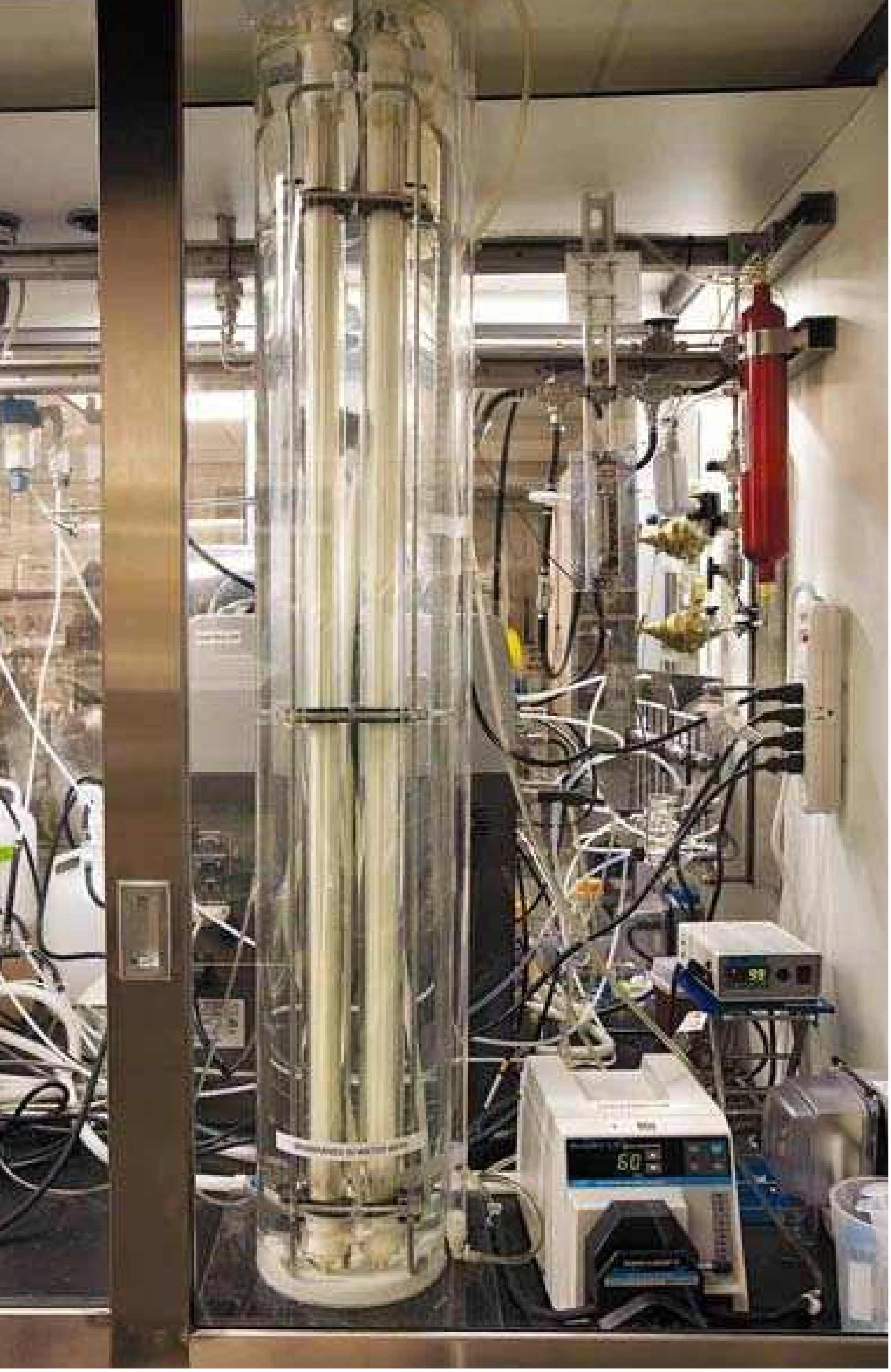
Tobey's tour begins at the far end of the laboratory in two small rooms full of pipes, throbbing pumps, and pressurized tanks—all used to process synthesis gas (also known as syngas), a mixture of carbon dioxide, carbon monoxide, and hydrogen. This is the thermochemical part of Coskata's process: in a well-known technique called gasification, a series of chemical reactions carried out at high temperatures can produce syngas from almost any organic material. Ordinarily, chemical catalysts are then used to convert the syngas into a mixture of alcohols that includes ethanol. But making such a mixture is intrinsically inefficient: the carbon, hydrogen, and oxygen that go into the other alcohols could, in principle, have gone into ethanol instead. So this is where Coskata turns from chemistry to biology, using microbes to convert the syngas to ethanol more efficiently.

Down the hall from the syngas-processing equipment, Tobey shows off the petri dishes, flasks, and sealed hoods used to develop species of bacteria that eat syngas. The bioreactors sit at the far end of the room. Inside the bioreactors' tubes, syngas is fed directly to the bacteria, which produce a steady stream of ethanol.

Coskata's technology could be a big deal. Today, almost all ethanol made in the United States comes from corn grain; because cultivating corn requires a lot of land, water, and energy, corn-derived ethanol does little to reduce greenhouse-gas emissions and can actually cause other environmental damage, such as water pollution. Alternative ethanol sources, such as switchgrass, wood chips, and municipal waste, would require far fewer resources. But so far, technology for processing such materials has proved very expensive. That's why Coskata's low-cost technique has caught the attention of major investors, including General Motors, which earlier this year announced a partnership with the startup to help deploy its technology on the commercial scale worldwide.

ETHANOL FACTORY Coskata vice president Richard Tobey (top) stands before bales of hay, a feedstock that his company's new technology can efficiently convert into ethanol. He's holding the centerpiece of that technology, a bioreactor. In the version of the reactor that's currently in operation (right), water flows around thin fibers coated with colonies of bacteria. Since the fibers are hollow (above), they can deliver gases that feed the bacteria. The bacteria convert these gases into ethanol, which flows out of the bioreactor mixed with water. The water is removed to yield fuel-grade ethanol that's 99.7 percent pure (far right).

PHOTOGRAPHS BY THOMAS CHADWICK



SIPPING ETHANOL

Combining thermochemical and biological approaches in a hybrid system can make ethanol processing cheaper by increasing yields and allowing the use of inexpensive feedstocks. But Coskata's process has another advantage, too: it's fast. Though others have also developed syngas-fed bioreactors, Tobey says, they have been too slow. That's because the bacteria are suspended in an aqueous culture, and syngas doesn't dissolve easily in water. Coskata's new bioreactor, however, delivers the syngas to the bacteria directly.

The thin fibers packed into the bioreactor serve two functions. First, they act as scaffolding: the bacteria grow in biofilms on the outside of the fibers. Second, they serve as a delivery mechanism for the syngas. Even though each fiber is not much bigger than a human hair, Tobey says, it acts like a tiny plastic straw. The researchers pump syngas down the bores of the hollow fibers, and it diffuses through the fiber walls to reach the bacteria. Water flows around the outside of the fibers, delivering vitamins and amino acids to the bacteria and carrying away the ethanol the bacteria produce. But the water and the syngas, Tobey says, never meet.

Coskata has also improved the last steps of the process, in which the ethanol is separated from the water. Ordinarily, this is done using distillation, which is expensive and consumes 30 percent as much energy as burning the ethanol will release. Coskata instead uses a modified version of an existing technology called vapor permeation. Vapor permeation uses hydrophilic membranes to draw off the water, leaving pure ethanol behind. It also consumes half as

RAISING MICROBES Coskata's ethanol-producing bacteria can't breathe oxygen, so researchers working to improve them use sealed, atmosphere-controlled hoods (above). Getting the most from the bacteria means optimizing the nutrition they receive. So the researchers grow the bacteria in a suspended culture (large flasks, right) and feed them different mixes of nutrients (small bottles with red caps) to determine which combinations result in the highest levels of ethanol production.

much energy as distillation per gallon of fuel. Vapor permeation is difficult to use with most biological manufacturing processes, Tobey says, because biomass fed to the microörganisms washes out with the water and can clog up the system. But in Coskata's process, the bacteria feed only on syngas, not on biomass. So no extra filtration is required to make vapor permeation work.

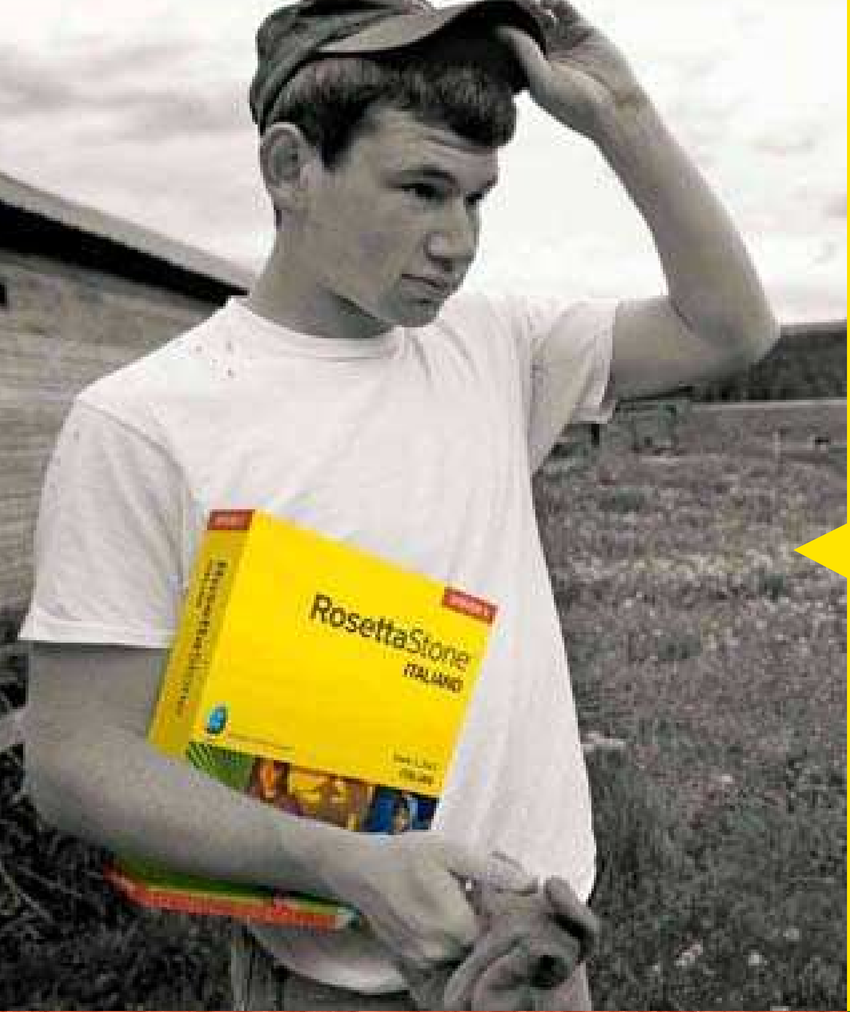
BETTER BUGS

Coskata continues working on its bacteria, trying to increase the amount of ethanol they can produce. The company now uses varieties of *Clostridium*, a genus that includes a species that make botulism toxin and another that processes manure on farms. Coskata has started building an automated system for screening new strains of *Clostridium* according to their ability to make ethanol. Along the way, it has had to develop techniques for protecting its bacteria from being exposed to oxygen; the bacteria are anaerobic, and oxygen kills them at about the same concentrations at which carbon monoxide kills humans. The automated system should allow the company to sort through 150,000 new strains a year, up from a few thousand now.

The researchers can go only so far by sorting through random variations, however. Eventually, Tobey hopes to begin manipulating the microbes' genes directly, activating only those that improve ethanol production. Such engineering is fairly common now, but the *Clostridium* bacteria that Coskata uses haven't been studied much. So although Tobey knows what chemical steps the bacteria use to transform syngas into ethanol, he doesn't yet know the details of how genes regulate this process, and what role these genes play in the general processes that keep the bacteria alive. What's more, effective ways of manipulating the genes in these particular bacteria haven't yet been developed.

Even as Coskata continues to improve its microbes, it is planning to move the fuel production process out of the lab and scale it up to the commercial level. With the help of GM and other partners, the company will build a facility that's able to produce 40,000 gallons of ethanol per year. Coskata representatives say construction will begin within the year. The company's bioreactors should make it easy to adapt the technology to a larger scale, Tobey says; they can simply be lined up in parallel to achieve the needed output volumes. The next two or three years will reveal whether Coskata's process can start to replace significant amounts of gasoline with cheap ethanol. TR

KEVIN BULLIS IS NANOTECHNOLOGY AND MATERIALS SCIENCE EDITOR OF *TECHNOLOGY REVIEW*.



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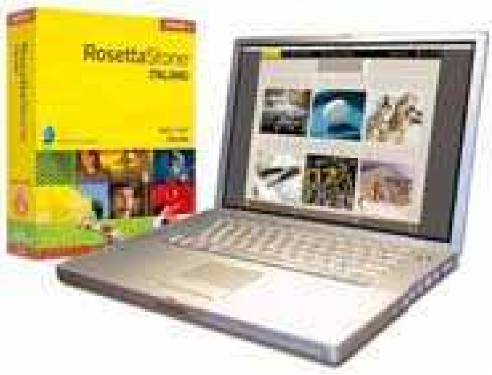

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FROM THE LABS

INFORMATION TECHNOLOGY

Bionic Eye

AN ELECTRONIC CONTACT LENS COULD ACT AS AN ON-EYE DISPLAY OR A BIOSENSOR

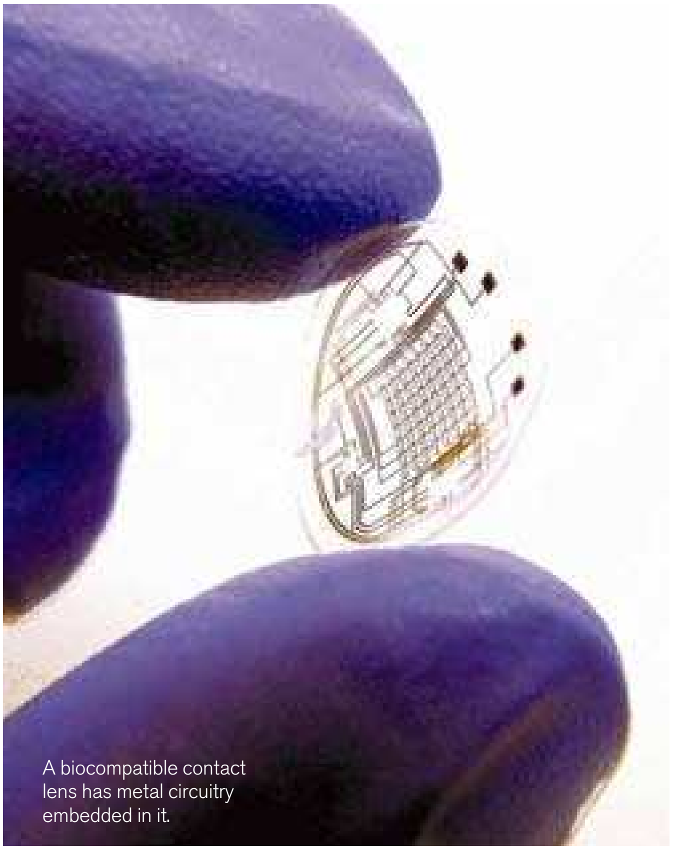
SOURCE: "CONTACT LENS WITH INTEGRATED INORGANIC SEMICONDUCTOR DEVICES"
Babak Parviz et al.
IEEE International Conference on Micro Electro Mechanical Systems, January 13–17, 2008, Tucson, AZ

Results: Researchers at the University of Washington have built a biocompatible contact lens with electronics and optoelectronics embedded in it. In preliminary studies in which the device was not turned on, a rabbit wearing it suffered no adverse effects.

Why it matters: A contact lens with both a wireless receiver and a display built into it could superimpose important information on objects in a soldier's field of view. It could tell cell-phone users where incoming calls are coming from, and eventually it might even serve as a video screen. A lens with embedded sensors could detect critical biomarkers that indicate disease, giving doctors a noninvasive diagnostic tool and helping them track a patient's health over time.

Methods: The lens was made from polyethylene terephthalate (the plastic used in beverage bottles), which was covered with metal wires in order to connect light-emitting diodes. The researchers used chemicals to carve out circular indentations in which the LEDs would be placed. Because electronics are made at temperatures high enough to melt plastic, the LEDs were fabricated separately and transferred to the lens. The device was then coated with a biocompatible material and shaped.

Next steps: Right now, the LEDs are about 300 micrometers in diameter, and no more than 16 working LEDs have been produced on a lens. LEDs this size tend to break during the lens-shaping process, so the researchers will try to shrink them to 30 micrometers, which could make possible a lens display of a few hundred pixels. Also, the team needs to make sure that the electronic lens is safe for the eye when it is turned on.



A biocompatible contact lens has metal circuitry embedded in it.

UNIVERSITY OF WASHINGTON

3-D Light Channels

MINIATURE WAVEGUIDES CAN STEER LIGHT THROUGH SOLID MATERIALS IN THREE DIMENSIONS

SOURCE: "EMBEDDED CAVITIES AND WAVEGUIDES IN THREE-DIMENSIONAL SILICON PHOTONIC CRYSTALS"
Paul V. Braun et al.
Nature Photonics 2: 52–56

Results: Researchers at the University of Illinois, Urbana-Champaign, have developed a laser technique that can carve detailed, three-dimensional waveguides into silicon photonic crystals, materials with regularly spaced holes that can control the motion of photons.

Why it matters: Optical chips, which use photons instead of electrons to carry information, could speed up computers, because photons travel faster than electrons. They could also cheaply increase bandwidth in telecommunications equipment. Previously, researchers made flat, two-dimensional waveguides using lithography, a common chipmaking technique. But a way to make three-dimensional waveguides gives researchers more freedom in designing optical circuits: light can be bent around corners, and optical materials can be layered.

Methods: To build their photonic crystal, the researchers began by packing silica beads together to form a three-dimensional matrix. They immersed the beads in a light-sensitive monomer, which flowed into the spaces between the beads. A precise

laser beam solidified some of the monomer into "paths" of polymer. Then the researchers rinsed the structure, removing the excess monomer, and filled the remaining spaces between beads with silicon. Finally, they used an acid to dissolve the beads and the polymer, leaving a silicon structure with periodic holes where the beads had been and channels—waveguides—where the polymer paths had been.

Next steps: The researchers are creating waveguide designs that are more complex. They will also explore ways to build functional optical circuits.

NANOTECHNOLOGY

Better Lithium-Ion Electrodes

SILICON NANOWIRES COULD INCREASE THE STORAGE CAPACITY OF BATTERIES

SOURCE: "HIGH-PERFORMANCE LITHIUM BATTERY ANODES USING SILICON NANOWIRES"
Yi Cui et al.
Nature Nanotechnology 3: 31–35

Results: Researchers at Stanford University demonstrated that silicon nanowires used as anodes in lithium-ion batteries have five to eight times the energy-storage capacity of the graphite anodes normally used in the batteries. The researchers also showed that the nanowires can absorb and release lithium ions quickly over many cycles without breaking apart.

Why it matters: The advance could lead to greater storage capacity in lithium-ion batteries. Such batteries work by shuttling lithium ions between the cathode and the anode (the positive and negative electrodes) as the batteries are charged and discharged. Silicon has long been considered a promising electrode material because it can, in theory, hold 10 times as many lithium ions as graphite. But as silicon absorbs lithium ions, it swells to many times its original volume. Over several cycles, this normally causes silicon electrodes to break apart and stop functioning properly. The silicon nanowires, however, were able to swell to four times their original size and remain intact, demonstrating that silicon could be a practical material for battery electrodes.

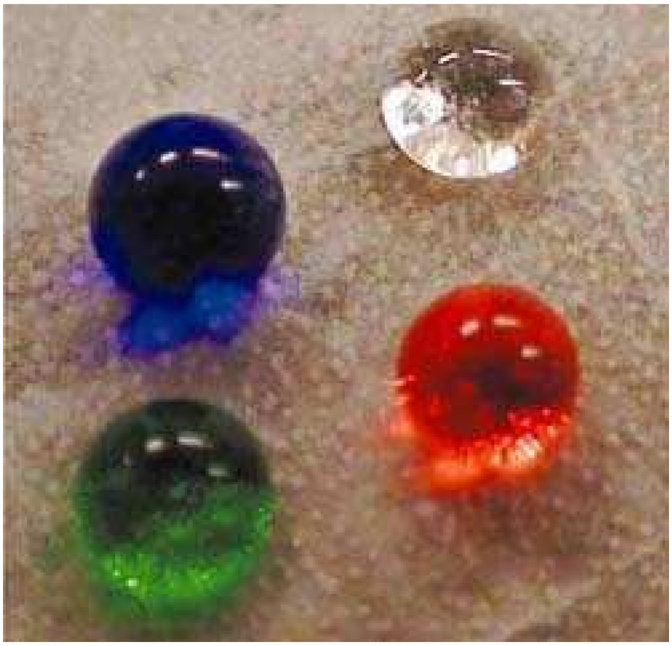
Methods: The researchers distributed gold nanoparticles on a stainless-steel substrate. When they exposed the nanoparticles to silane, a gas containing silicon, the gold catalyzed the growth of silicon nanowires. The researchers then tested the nanowire electrodes. They also studied the composition and structure of the nanowires.

Next Steps: The researchers are developing other ways to make the silicon nanowires, with the goal of finding techniques that are less expensive and thus potentially more practical for commercial manufacturing. Better cathodes also need to be developed before the full benefits of the new anode materials can be realized.

Coating That Repels Oil

NEW MATERIALS CLEAN THEMSELVES, ELIMINATING THE NEED FOR SOAP AND WATER

SOURCE: "DESIGNING SUPER-OLEOPHOBIC SURFACES"
Gareth H. McKinley, Robert E. Cohen, et al.
Science 318: 1618–1622



A new coating made of microscopic threads can repel a variety of liquids, including water (dyed blue), methanol (green), octane (red), and methylene iodine (clear).

Results: Researchers at MIT and the Air Force Research Laboratory at Edwards Air Force Base in California have made novel materials that cause oil to bead up and form near-spherical droplets that easily roll or even bounce off surfaces. The researchers also analyzed the mechanisms behind the materials' oil-repellent properties and developed design rules that could be useful for making similar materials in the future.

Why it matters: The researchers' oil-repellent surfaces could make rubber hoses and engine seals more durable by preventing them from absorbing oil and swelling. Eventually, the detailed design rules could help scientists develop materials for other applications—such as transparent, self-cleaning displays, something cell-phone companies have been working on for years.

Methods: The air force researchers first developed new molecules containing high concentrations of fluorine atoms. When applied to a surface in a thin film, the molecules cause oil to bead up. The MIT researchers found a

ANISH TUTEJA AND WONJAE CHOI, MIT

way to blend these molecules with commercial polymers and enhanced the liquid-repelling properties of the blended material by spinning it into microscopic threads. These threads accumulate on a surface, creating a rough, air-trapping network that alters the contact angle between the material and oil, causing the oil to bead up even more than it would on a flat film.

Next Steps: The polymeric surfaces aren't ideal: for one thing, they're opaque. The researchers hope that the design rules they developed will allow other researchers to create super-oil-repellent materials that overcome current limitations.

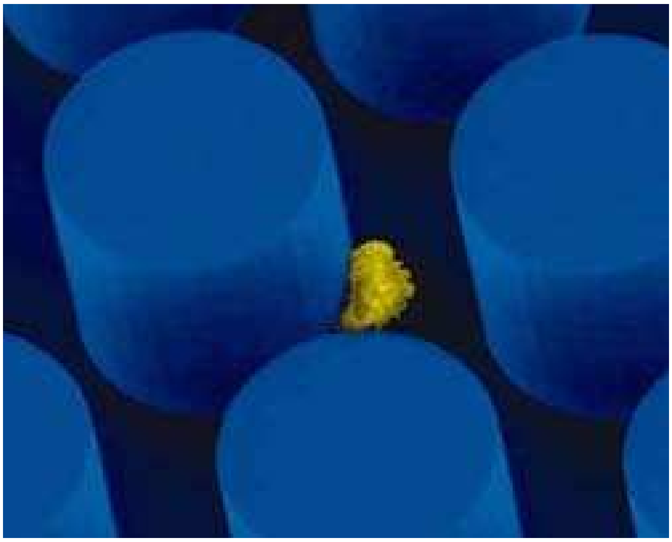
BIOTECHNOLOGY

Test for Cancer Cells in Blood

AN INEXPENSIVE MICROFLUIDIC CHIP COULD LEAD TO EARLIER CANCER DETECTION AND TREATMENT

SOURCE: "ISOLATION OF RARE CIRCULATING TUMOUR CELLS IN CANCER PATIENTS BY MICROCHIP TECHNOLOGY"
Mehmet Toner et al.
Nature 450: 1235–1239

Results: A microfluidic device designed by researchers at Massachusetts General Hospital in Boston can detect very low blood levels of cells from malignant tumors. In initial tests, the low-cost device detected such cells in the blood of all but one of 116 patients with various types of cancer.



When blood flows through the microfluidic device, cancer cells in the blood (shown in yellow) stick to microscopic posts lining the chip (shown in blue).

MASSACHUSETTS GENERAL HOSPITAL BIOMEMS RESOURCE CENTER

Why it matters: A malignant tumor continually sheds cells into the bloodstream, spreading cancer to other tissues. Changes in the number of circulating cancer cells indicate changes in the size of the tumor during treatment. A cheap way to detect and monitor those cancer cells could allow doctors to regularly assess the effectiveness of treatment, as they do by measuring levels of viral RNA in HIV patients. Researchers can also examine cells captured on the microfluidic chip for molecular markers that suggest a more aggressive form of cancer or a type of tumor that will respond to specific drugs.

Methods: The device consists of a business-card-size silicon chip dotted with 80,000 microscopic posts. Each post is coated with a molecule that binds to a specific protein found on most cells originating from solid tumors, such as those found in breast, lung, and prostate cancer. As blood flows through small channels in the chip, tumor cells stick to the posts.

Next steps: Larger clinical trials involving patients with lung and prostate cancer will help determine how best to use the chip.

New Stem Cells Cure Disorder in Mice

THE FINDINGS DEMONSTRATE HOW THESE CELLS COULD BE USED IN HUMAN THERAPIES

SOURCE: "TREATMENT OF SICKLE CELL ANEMIA MOUSE MODEL WITH IPS CELLS GENERATED FROM AUTOLOGOUS SKIN"
Tim M. Townes, Rudolf Jaenisch, et al.
Science 318: 1920–1923, published online December 6, 2007

Results: Scientists have cured a blood disease in mice using cells from the animals' tails. A new technique that does not require the use of embryos enabled the researchers to reprogram the cells to behave like embryonic stem cells.

Why it matters: The findings are the first to demonstrate the potential of such cells, known as induced pluripotent cells, in treating disease. The cells have been the source of great excitement among both researchers and the public because they hold therapeutic promise and because they sidestep the major ethical concern associated with embryonic stem cells: the destruction of embryos.

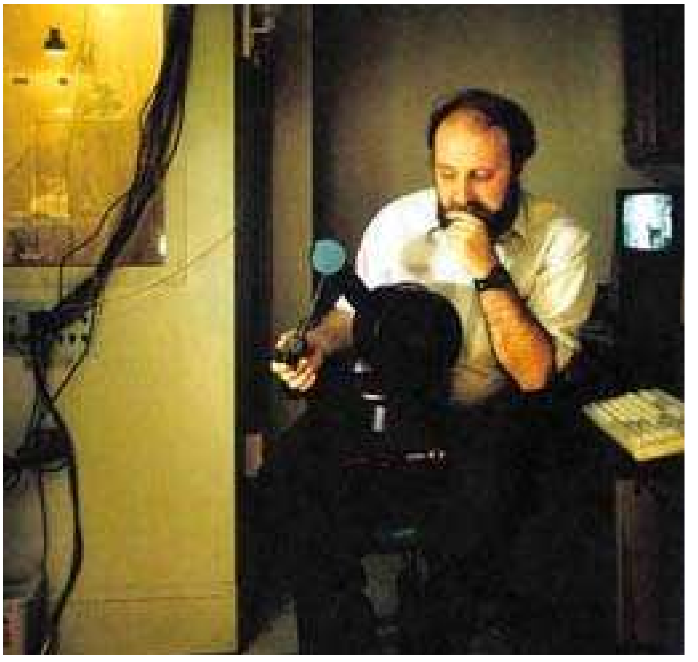
Methods: Rudolf Jaenisch and his colleagues at the Whitehead Institute for Biomedical Research in Cambridge, MA, reprogrammed the mouse tail cells to express four genes that are normally active only during embryonic development. After correcting the genetic defect responsible for sickle-cell anemia, they treated the cells with growth factors to trigger the development of blood-forming stem cells. Mere days after the researchers injected the stem cells into the animals' bone marrow, symptoms of the disease had reversed.

Next steps: Scientists are concerned that the mechanism used to reprogram the cells to make them pluripotent could increase the risk of cancer. To make the cells safe for human use, the researchers are developing alternative methods.

The Power of Thought

MIGUEL NICOLELIS CONTINUES TO LEAD THE WAY IN NEURAL-IMPLANT TECHNOLOGY.

By MICHAEL PATRICK GIBSON



A 2001 *Technology Review* article described experiments done by Miguel Nicolelis, in which a monkey used brain signals to remotely control a simple robotic arm (shown in front of Nicolelis).

PATRICIA MCDONOUGH

In January a rhesus monkey named Idoya did what no other creature has done before: she made a robot walk just by thinking about it. All Idoya had to do was imagine taking a step, and the robot would actually take it.

At the behest of signals sent over the Internet from electrodes in Idoya's brain, the 200-pound robot began to walk on a treadmill in Kyoto, Japan. This while the monkey was on the other side of the world—in Miguel Nicolelis's lab at the Center for Neuroengineering at Duke University in Durham, NC. This telekinetic remote control was the latest achievement made possible by Nicolelis's research on a novel brain-machine interface—a technology singled out as one of the TR10 in 2001.

Nicolelis says his recent experiment shows that his neuroprosthetic system is close to fulfilling its promise of restoring mobility to paralyzed patients by means of an exoskeleton. This robotic support system would move limbs by the power of thought alone: a processor worn on the hip would translate brain signals into commands telling the exoskeleton to move however its wearer intended. In January, Nicolelis's group launched a project to build the exoskeleton.

When *Technology Review* wrote about Nicolelis in 2001, his work was still in its infancy. The implanted electrodes could record the activity of just 90 neurons; while that allowed a monkey to control a robotic arm, the quality of control would quickly deteriorate. Yet the results, as described by senior associate editor Antonio Regalado, were a breakthrough:

Belle, a nocturnal owl monkey small enough to fit comfortably in a coat pocket, blinks her outsized eyes as a technician plugs four connectors into the sockets installed in the top of her skull. In the next room, measurements of the electrical signals from some 90 neurons in Belle's brain pulse across the computer screen. Recorded from four separate areas of Belle's cerebral cortex, the signals provide a window into what her brain is doing as she reaches to touch one of four assigned buttons to earn her reward—a few drops of apple juice. Miguel Nicolelis, a Duke University neurobiologist who is pioneering the use of neural implants to study the brain, points proudly to the captured data on the monitor and says: "This readout is one of a kind in the world."

The same might be said of Nicolelis, who is a leader in a competitive and highly significant field. Only about a half-dozen teams around the world are pursuing the same goals: gaining a better understanding of how the mind works and then using that knowledge to build implant systems that would make brain control of computers and other machines possible. ...

Nicolelis's latest experiments ... show that by tapping into multiple neurons in different parts of the brain, it is possible to glean enough information to get a general idea of what the brain is up to. In Belle's case, it's enough information to detect the monkey's intention of making a specific movement a few tenths of a second before it actually happens. And it was Nicolelis's team's success at reliably measuring tens of neurons simultaneously over many months—previously a key technological barrier—that enabled the remarkable demonstration with the robot arm.

Nicolelis's recent experiment involved recording the activity of 500 neurons. To animate the proposed exoskeleton, he would like to send and receive information to and from up to 10,000 neurons—a difficult goal, but one he says can be reached. "The development of technology is not a straight line," he says. "But we're patient." TR

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